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14. ABSTRACT
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Implementation Strategies for Emerging Materials and Biotechnology

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Defence R&D Canada

Technical Report
DREA TR 2001-161
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Abstract

An implementation strategy for Emerging Materials and Biotechnology, one of twenty one new R&D activities identified in the Defence Research and Development Canada (DRDC) Technology Investment Strategy, is proposed. The proposal recommends four foci for this new activity; Focus A - Functional Materials for Transducers, Actuators, and Smart Structures, Focus B - Substitution of Conventional Materials by Tailored Polymers, Focus C - Synthesis of Military Materials by Molecular Manufacturing Techniques, and Focus D - Biotechnology for the Protection of CF Personnel. The selection of foci was based on surveys of approximately 50 experts in these fields and a limited literature review. Straw-man research activities and levels of effort (with guidance from ADM S&T) based on possible scenarios for future staffing are delineated. It is recommended that Focus A be implemented at both DREA and RMC, Focus B be implemented at DREA, Focus C at NRC/IAR, and Focus D at a new Section at DRES.

Résumé

Une stratégie d'exécution est proposée pour l'activité Matériaux nouveaux et biotechnologie, l'une des vingt et une nouvelles activités de R et D mentionnées dans la Stratégie d'investissement technologique de Recherche et développement pour la défense Canada (RDDC). Le projet recommande quatre thèmes pour cette nouvelle activité; le thème A - Matériaux fonctionnels pour transducteurs, actionneurs et structures intelligentes, le thème B - Remplacement des matériaux conventionnels par des polymères sur mesure, le thème C - Synthèse de matériaux militaires par des techniques de fabrication moléculaire, et le thème D - Biotechnologie pour la protection du personnel des FC. Le choix des thèmes a été basé sur une enquête auprès d'une cinquantaine d'experts dans ces domaines et une recherche documentaire limitée. On précise des activités de recherche fictives et l'ampleur de la participation (directives de SMA-ST) sur des scénarios éventuels pour la dotation future. On recommande que le thème A soit exécuté au CRDA et au CMR, le thème B au CRDA, le thème C à l'IRA du CNRC et le thème D à une nouvelle section du CRDS.

Executive summary

Defence Research and Development Canada (DRDC) developed a Technology Investment Strategy (TIS) to ensure that its portfolio of technological competencies would be both appropriate and adequate for the future needs of the Canadian Forces, as outlined in Defence Strategy 2020. The TIS identified 21 *R&D Activities* that would be required to address the outcomes needed for the CF of 2010 and beyond. Some of the R&D Activities are well known, and represent evolutions of existing R&D *Technologies*.[1] Others are new, or represent significant change from current Technologies. This report describes implementation strategies for one of the new Activities: Emerging Materials and Biotechnology.

Emerging Materials and Biotechnology (EM & BT) emerged from a slightly different Activity in the TIS: Emerging Materials and Bio Molecular Technology (EM & BMT). Both shared essentially the same definition and the first three *foci*, where foci define the scientific regimes of teams of science workers. These science workers are those who undertake the work defined in R&D thrusts, developed in consultation with the CF client. The following table defines EM & BT:

Definition: This activity (area of competency) reflects the increasing importance of advanced or novel materials, whether organic or in-organic, in military or civil systems. Most contemporary advances in materials technology are not a response to a requirement, but instead, a technology driver. This is particularly true for biotechnology, where certain applications would simply be infeasible without a biotechnological basis. Although this activity (area of competency) does not include the development of systems in the classical, linear RD & E sense, the conduct of technology demonstrations of application of emerging materials or biotechnology products would be necessary in addition to research in materials and biotechnology *per se*.

Approach

The present study was initiated by staff at DREV but the study was later transferred to DREA where the first author assumed responsibility for it. The authors surveyed approximately 50 experts, both nationally and abroad[2], and made a limited survey of the literature to develop an appreciation of the emerging materials and biotechnology fields.

The surveys and literature were used to assess the suitability of the foci first proposed in the TIS, and as a basis for amendment where appropriate. From this information, more detailed competencies were developed, together with straw-man research activities.

[1] In some respects, the choice of the word 'Activities' was unfortunate, for to many readers it implied 'program' rather than 'competency,' a confusion which raised concerns that a well-understood and appreciated, client-driven program formulation process was being changed.
[2] The authors visited DRDC Defence Research Establishments, RMC and civilian universities in Canada, NRC Institutes, and the UK Defence Evaluation and Research Agency

Levels of effort were established following guidance from ADM(S&T) on possible scenarios for future science worker staffing, as follows:

Scenario	DRDC Total Change in S&T FTEs	DRDC FTEs assigned to EM & BT	NRC/IAR FTEs assigned to EM & BT
Status quo	Nil	7 at DREA	3 at NRC/IAR[3]
Scenario 1	Redistribution	7 at DREA	3 at NRC/IAR
Scenario 2	Scenario 1 + 160[4]	7 at DREA	3 at NRC/IAR
Scenario 3	Scenario 1 +260	27 at DREA 20 at DRES	3 at NRC/IAR
Scenario 4	Scenario 1 + 360	27 at DREA 30 at DRES	3 at NRC/IAR

The Status Quo

Today there is very little EM & BT activity underway in DRDC program. Most activity is at DREA, either in the Dockyard Laboratories or within the Transducer Group, which exploits functional materials as drivers ('motors') in sonar transducers. DREA's Dockyard Laboratory (Pacific)'s activities are relatively new, courtesy of a TIF project on organic radar absorbing materials. The DREA activities are linked to university researchers, with the most important to date being at RMC, which maintains a materials characterization capability developed under earlier DREA sponsorship.

NRC conducts a program of molecular-level materials formulation and modeling in support of aero-engine coatings. Three of the nine IAR researchers are supported by DRDC-sponsorship.

Notwithstanding the general belief in the future importance of biotechnology, no DRDC-sponsored work in biotechnology is credited to EM & BT, although various TIF projects at DRES could be. Instead, these TIF projects are credited with supporting Chemical/Biological/Radiological Threat Assessment and Detection or Operational Medicine, but neither of these 'evolving' TIS activities provides the resources necessary to exploit the fruits of these TIF projects.[5]

[3] Three of nine IAR workers in this activity are DRDC-sponsored, thus three may be regarded as part of DRDC program. The IAR workers were not identified in the ADM(S&T) guidance, but are included here for completeness

[4] '160' represents 100 new FTEs plus 60 recovered from overheads through business efficiencies

[5] As of 30 November 2000, the DRDC Cooperative Planning and Management Environment (CPME) showed the ratio of TIF/TI at DRES in Client Group 6 as 1.1 for FY 00/01, 0.67 for FY 01/02, and 0.59 for FY 02/03 Such numbers raise doubts as to the ability of current program to adopt TIF activities after completion of projects

Recommendations

The following recommendations are presented in the form of definitions of foci, together with associated staffing levels, followed by descriptions of competencies and working relationships.

Focus A: Functional Materials for Transducers, Actuators, and Smart Structures: The performance of functional materials is a key constraint on performance of transducers (such as sonar projectors) and actuators and signature control devices (such as active machinery mounts). Introduction of functional materials with higher than hitherto strains can have far greater benefit than any amount of ingenuity with transducer geometry and could lead, ultimately, to the development of structures capable of optimal response to external loads, or for use as fluid dynamic controls.
FTEs Status quo through Scenario 2: 3 DREA (plus 1 RMC-funded professor) Scenario 3 & 4: 11 DREA, 4 RMC (plus 1 RMC-funded professor)

Focus A is now supported by three DRDC-funded positions at DREA together with an RMC professor. The TIS provides for identical growth in EM & BMT in scenarios 3 and 4, from which this plan assigns 15 FTEs to Focus A. Five new staff would be assigned to DREA's Dockyard Laboratory (Atlantic) to investigate functional materials, and a further 1 and 2 respectively to DREA's Transducer Group and Warship Signatures and Safety Section to facilitate application of functional materials to transducers and smart structures. Additionally, Scenarios 3 and 4 would support a research chair, a post-doctoral fellow, and two research assistants at RMC to reinforce the functional materials characterization effort now extant there under the leadership of Professor Binu Muhkergee. NRC/IAR has a well-established program in smart structures, but assigns its resources to the Platform Performance and LCM activity in the TIS.

Focus A would support R&D thrusts through a network of researchers both within and outside DRDC. The RMC cell would be of key importance in information capture, since as 'DND academics' RMC staff are able to interact easily with both civil academia and the US Defence research community. Professor Muhkergee has, for example, built strong relationships with the US Office of Naval Research. DREA's Dockyard Laboratory (Atlantic) would be a pivotal player within DREA, providing support to transition of functional materials to structural and transducer applications. Finally, the DREA Transducer Group would benefit from strategic relationships with industries, such as the American Etrema Company, which controls IP for TERFENOL, and the Canadian company, Sensor Technologies, which is a licensee of DREA-generated IP.

Growth in Focus A would be expected to facilitate collaboration under the TTCP MAT Group.

Focus B: Substitution of Conventional Materials by Tailored Polymers: Such substitutions demand both careful selection and formulation of materials and re-examination of design parameters, so that materials capabilities are exploited optimally. Tailored polymers will require development of advanced modeling techniques for the prediction of mechanical or chemical performance, and estimation of feasibility of formulation.
FTEs Status quo through Scenario 2: 4 DREA Scenarios 3 & 4: 12 DREA

Focus B is now supported by four DRDC-funded positions at DREA, with those in Dockyard Laboratory (Atlantic) supporting noise reducing polymers, and those at Dockyard Laboratory (Pacific) supporting organic radar absorbing materials. Scenarios 3 and 4 would support growth at both Dockyard Laboratories, with eight FTE's addressing 'polymers by design' in Halifax, and four FTEs supporting functional organic coatings and appliqués in Esquimalt. Both Focii A and B are dependent upon redevelopment of DREA's Dockyard Laboratory (Atlantic) to house the growth in personnel.

The Dockyard Laboratory (Atlantic) has a history of collaboration with NRC's Industrial Materials Institute, and would probably strengthen this relationship with further resources. The Dockyard laboratory (Pacific) is expected to benefit from a recent exchange with the US Naval Surface Warfare Centre (Carderock) on the subject of radar absorbing materials.

Growth in Focus B would be expected to facilitate collaboration under the TTCP MAT Group.

Focus C (revised): Synthesis of Military Materials by Molecular Manufacturing Techniques: Military systems, particularly aeronautical, are significant users of high performance materials for tribological or combustion applications, but the most common of such materials are increasingly subject to environmental censure. Typically, such high-performance applications require combinations of toughness and hardness that are not feasible through bulk metallurgy, but such combinations of properties can be achieved through molecular-level material assembly. It is expected that work will initially focus on aeronautical applications, with spin-off to other applications and problems as experience develops.
FTEs Status quo through Scenario 4: 9 NRC/IAR (3 DRDC-funded, 6 NRC-funded)

Initial versions of Focus C included manufacturing through bio-molecular technology, perhaps in recognition of the potential of biomimetics; however, reference to biotechnology was dropped in favour of a more capable biotechnology-directed Focus D.

Focus C is now limited to molecular techniques alone, as conducted by NRC IAR. Work of this nature is directed towards first principles modeling and laboratory-level production of test materials. The leading application is aero engine high-temperature coatings; the 2001 TIF program supports such a project from IAR (Zhao: Modeling Single-Crystal Superalloy Properties).

Focus D (new): Biotechnology for the Protection of CF Personnel: CF contingency and coalition missions take personnel into a broad range of environments presenting a broad challenge of endemic disease and other chemical and biological hazards. Biotechnology is the enabling technology which will provided needed advances in treatments, detection and identification technologies and diagnostics, to provide the Force Health Protection required by the CF. Biotechnology also has applications in materials sciences and in the production of coatings and materials which can improve permeability characteristics, filtration capabilities and performance in adverse environments.
FTEs Status quo through Scenario 2: no resources Scenario 3: 20 DRES Scenario 4: 30 DRES

Focus D reflects a need for a more classical biotechnology effort within the DRDC program. It is concentrated at DRES to position it close to two key 'client' activities: Chemical/Biological/Radiological Threat Assessment and Detection or Operational Medicine. Focus D would provide supporting technology to a number of ongoing DRES efforts: the Detection and Identification Group, the Personal Protection Group, and the Preventative Medicine Group.[6]

International collaboration under Focus D would tend to be directed towards CBD, whether under TTCP or bi-lateral fora.

Focus D would require considerable capital support: the staffing plan assumes the availability of additional, independent level 3 bio-labs, both to deal with increased demand, and to enable continuous availability. Current facilities must close annually for re-certification; with independent labs such closures might be staggered.

Focus D will provide a welcome addition to DRDC's capabilities, however it comes at the cost of limiting potential benefits in 'conventional' emerging materials to two fairly narrow areas; albeit ones staffed at a level appropriate to support real technological advancement and meaningful collaboration with allies. Foci A and B will enable more effective collaboration under TTCP MAT Group, but certainly will not be able to respond to more than a few of the opportunities currently being refused.

Nethercote, W. and Hiltz, J. 2001. Implementation Strategies for Emerging Materials and Biotechnology. DREA TR 2001-161. Defence Research Establishment Atlantic.

Sommaire

Recherche et développement pour la défense Canada (RDDC) a élaboré une Stratégie d'investissement technologique (SIT) pour permettre que son portefeuille de compétences technologiques soit approprié et adéquat pour les besoins futurs des Forces canadiennes, comme il est décrit dans la Stratégie de défense 2020. Dans la SIT, on a précisé 21 *activités de R et D* nécessaires pour obtenir les résultats dont les FC auront besoin en 2010 et au-delà. Certaines de ces activités sont bien connues et constituent des évolutions de *technologies* de R et D existantes.[1] D'autres sont nouvelles ou sont des technologies qui ont été profondément modifiées. Le présent rapport décrit les stratégies d'exécution de l'une des nouvelles activités : Matériaux nouveaux et biotechnologie.

L'activité Matériaux nouveaux et biotechnologie (MN et BT) est issue d'une activité légèrement différente dans la SIT : Matériaux nouveaux et technologie biomoléculaire (MN et TBM). Les deux ont essentiellement la même définition et partagent les trois premiers *thèmes*; les thèmes définissent les régimes scientifiques des équipes de scientifiques. Ces scientifiques sont ceux qui réalisent les travaux définis dans les vecteurs de la R et D élaborés en consultation avec les clients des FC. Le tableau suivant définit l'activité MN et BT :

Définition: Cette activité (aire de compétence) reflète l'importance croissante des matériaux avancés ou nouveaux, qu'ils soient organiques ou inorganiques, dans les systèmes militaires ou civils. La plupart des progrès en matière de technologie des matériaux de nos jours ne proviennent pas de besoins, mais apparaissent plutôt sous la poussée des technologies elles-mêmes. Cela est particulièrement vrai de la biotechnologie; en effet, certaines applications seraient tout simplement irréalisables sans la biotechnologie. Bien que cette activité (aire de compétence) ne comprenne pas le développement de systèmes dans le sens classique et linéaire de RD et I, la tenue de démonstrations de technologies d'application de matériaux nouveaux ou de produits de la biotechnologie serait nécessaire outre la recherche sur des matériaux et la biotechnologie en soi.

Approche

L'étude actuelle a été amorcée par le personnel du CRDV, mais elle a été plus tard confiée au CRDA, où le premier auteur en a assumé la responsabilité. Les auteurs ont demandé l'avis d'une cinquantaine d'experts, tant à l'échelle nationale qu'à l'étranger[2] , et

[1] Sous certains angles, le choix du terme « activités » est mal choisi, car pour de nombreux lecteurs, il fait allusion à un « programme » plutôt qu'à une « aire de compétence », ce qui a semé la confusion et a fait croire qu'un processus de formulation de programme orienté vers le client, bien connu et apprécié faisait l'objet d'un changement

[2] Les auteurs ont visité les centres de recherche pour la défense de RDDC, le CMR et des universités civiles au Canada, des instituts du CRNC et la Defence Evaluation and Research Agency du R.-U.

ont effectué une recherche documentaire limitée pour obtenir une vue d'ensemble des domaines des matériaux nouveaux et de la biotechnologie.

Les enquêtes et la recherche documentaire ont servi à évaluer la pertinence des thèmes proposés au préalable dans la SIT et pour y apporter des modifications au besoin. À partir de ces données, des compétences plus détaillées ont été élaborées, ainsi que des activités de recherche fictives. L'ampleur de la participation a été établie à partir de directives de SMA-ST sur des scénarios éventuels pour la dotation future du personnel scientifique de la façon suivante :

Scénario	**Changements totaux dans les ETP en S et T de RDDC**	**ETP de RDDC affectés à MN et BT**	**ETP affectés par l'IRA du CNRC à MN et BT**
Statu quo	Rien	7 au CRDA	3 à l'IRA-CNRC[3]
Scénario 1	Redistribution	7 au CRDA	3 à l'IRA-CNRC
Scénario 2	Scénario 1 + 160[4]	7 au CRDA	3 à l'IRA-CNRC
Scénario 3	Scénario 1 +260	27 au CRDA 20 au CRDS	3 à l'IRA-CRNC
Scénario 4	Scénario 1 + 360	27 au CRDA 30 au CRDS	3 à l'IRA-CRNC

Le statu quo

À l'heure actuelle très peu d'activités de MN et BT sont en cours dans le cadre du programme de RDDC. La plupart des activités sont réalisées au CRDA, soit au laboratoire du chantier naval ou au sein du Groupe des transducteurs, qui exploite des matériaux fonctionnels comme pilotes (« moteurs » dans les transducteurs sonars. Les activités du laboratoire du chantier naval du Pacifique sont relativement nouvelles, dans le cadre d'un projet du FIT sur les matériaux organiques absorbant les ondes. Les activités du CRDA sont liées à des chercheurs universitaires, les plus importantes à ce jour étant réalisées au CMR qui abrite un service de caractérisation des matériaux financé auparavant par le CRDA.

Le CNRC applique un programme de formulation et de modélisation de matériaux à l'échelle moléculaire pour les revêtements de moteurs d'aéronef. Trois des neuf chercheurs de l'IRA sont financés par RDDC.

Même si l'on croit généralement en l'importance de la biotechnologie pour l'avenir, aucun projet de biotechnologie financé par RDDC n'est affecté à l'activité MN et BT, bien que divers projets de FIT puissent l'être au CRDS. Ces projets de FIT ont plutôt été affectés

[3] Trois des neuf employés de l'IRA qui participent à cette activité sont financés par RDDC, on peut donc les considérer comme faisant partie du programme de RDDC Les employés de l'IRA n'ont pas été inclus dans les directives de SMA-ST, mais ils le sont ici dans le but de donner un tableau complet.

[4] Le nombre « 160 » représente 100 nouveaux ETP plus 60 autres qui sont devenus surnuméraires par suite de l'efficience de l'organisation.

aux domaines de l'évaluation et de la détection de la menace chimique, biologique ou radiologique ou encore de la médecine opérationnelle, mais aucune de ces nouvelles activités de la SIT ne fournit les ressources nécessaires pour exploiter les fruits ce des projets de FIT.[5]

Recommandations

Les recommandations suivantes sont présentées sous la forme de définitions des thèmes; on y précise aussi les niveaux de dotation associés, puis les compétences et les relations de travail.

Thème A : Matériaux fonctionnels pour transducteurs, actionneurs et structures intelligentes : La performance des matériaux fonctionnels est une des principales propriétés qui influence le rendement des transducteurs (les projecteurs sonar, par exemple), des actionneurs et des dispositifs de contrôle de signature (les montages actifs des machines, par exemple). L'introduction de matériaux fonctionnels possédant une résistance plus élevée aux contraintes pourrait apporter des avantages beaucoup plus considérables que ceux découlant de l'ingéniosité à modifier la géométrie d'un transducteur, et cela pourrait finalement déboucher sur la mise au point de structures capables d'opposer une réaction optimale aux charges externes, ou pouvant être utilisées comme contrôles dynamiques des fluides.
ETP Statu quo à scénario 2 : 3 au CRDA (plus 1 poste de professeur financé par le CMR) Scénario 3 et 4 : 11 au CRDA, 4 au CMR (plus 1 poste de professeur financé par le CMR)

Le thème A est maintenant exploité par trois postes financés par RDDC au CRDA et par un professeur du CMR. La SIT prévoit une croissance identique de l'activité MN et BT dans les scénarios 3 et 4, à partir desquels le plan attribue 15 ETP au thème A. Cinq nouveaux employés seraient affectés au laboratoire du chantier naval de l'Atlantique du CRDA pour étudier les matériaux fonctionnels, un employé serait affecté au Groupe des transducteurs du CRDA et 2 autres seraient affectés à la Section des signatures et de la sécurité des bâtiments de guerre pour faciliter l'application des matériaux fonctionnels aux transducteurs et aux structures intelligentes. En outre, les scénarios 3 et 4 prévoient une chaire de recherche, un boursier de recherches post-doctorales et deux assistants à la recherche au CMR pour accroître l'effort de caractérisation des matériaux fonctionnels maintenant sous la direction du professeur Binu Muhkergee. L'IRA du CNRC a un programme bien établi dans le domaine des structures intelligentes, mais il affecte ses ressources au Rendement des plate-formes et à la Gestion du cycle de vie dans la SIT

[5] Au 30 novembre 2000, l'environnement de gestion et de planification en collaboration (EGPC) de RDDC a montré que le ratio de FIT/IT au CRDS dans le groupe de clients 6 était 1,1 pour l'exercice 00-01, 0,67 pour l'exercice 01-02 et 0,59 pour l'exercice 02-03 Ces chiffres mettent en doute la capacité du programme actuel d'adopter des activités de FIT après l'achèvement des projets.

Le thème A supporterait les vecteurs de R et D par l'entremise d'un réseau de chercheurs, tant à l'intérieur qu'à l'extérieur de RDDC. La cellule du CMR aurait une importance capitale dans la collecte de renseignements, car le personnel universitaire du MDN peut facilement échanger avec le personnel des universités civiles et la communauté de recherche du département américain de la Défense. Ainsi, le professeur Muhkergee entretient des rapports étroits avec le US Office of Naval Research. Le laboratoire du chantier naval de l'Atlantique du CRDA serait un intervenant central au sein du CRDA, appuyant la transition des matériaux fonctionnels aux applications structurales et aux transducteurs. Enfin, le Groupe des transducteurs du CRDA profiterait de relations stratégiques avec l'industrie, comme la compagnie américaine Etrema qui possède le brevet pour le TERFENOL et la compagnie canadienne Sensor Technologies, qui détient une licence pour un brevet obtenu par le CRDA.

La croissance du thème A serait de nature à faciliter la collaboration dans le Groupe de MAT du PCT.

Thème B : Remplacement des matériaux conventionnels par des polymères sur mesure : Ce genre de substitution demande une sélection et une formulation soigneuses des matériaux et un nouvel examen des paramètres de conception, de manière à ce que les capacités des matériaux soient exploitées au maximum. Les polymères sur mesure exigeront la mise au point de techniques de modélisation avancées permettant de prévoir la performance mécanique et chimique du produit et d'estimer la faisabilité de la formulation.
ETP Statu quo au scénario 2 : 4 au CRDA Scénarios 3 et 4: 12 au CRDA

Le thème B est maintenant exploité par quatre postes financés par RDDC au CRDA, ceux du laboratoire du chantier naval de l'Atlantique qui exploite les polymères de réduction du bruit, et ceux du laboratoire du chantier naval du Pacifique, qui exploite les matériaux organiques absorbant les ondes radar. Les scénarios 3 et 4 soutiendraient la croissance aux deux laboratoires du chantier naval, avec huit ETP étudiant les polymères sur mesure à Halifax et quatre ETP étudiant les revêtements organiques fonctionnels et les appliqués à Esquimalt. Les thèmes A et B nécessiteront l'agrandissement du laboratoire du chantier naval de l'Atlantique du CRDA pour qu'il puisse recevoir un effectif accru.

Le laboratoire du chantier naval de l'Atlantique collabore depuis un certain temps avec l'Institut des matériaux industriels du CNRC, et il serait probablement en mesure d'accroître cette collaboration avec plus de ressources. Le laboratoire du chantier naval du Pacifique devrait bénéficier d'un échange récent avec le US Naval Surface Warfare Center (Carderock) dans le domaine des matériaux absorbant les ondes radar.

La croissance du thème B devrait faciliter la collaboration dans le Groupe de MAT du PCT.

Thème C (révisé) : Synthèse de matériaux militaires par des techniques de fabrication militaire : Les systèmes militaires, notamment en aéronautique, sont des utilisateurs importants de matériaux de haute performance pour des applications tribologiques ou de combustion, mais les plus courants de ces matériaux sont de plus en plus soumis à la censure environnementale. Habituellement, ces applications de haute performance exigent en même temps des propriétés de résistance et de dureté qu'il n'est pas possible d'obtenir par la métallurgie classique, mais qu'on peut obtenir par un assemblage de matériaux à l'échelle moléculaire. On prévoit que les travaux porteront au début sur des applications en aéronautique, puis qu'ils auront des retombées sur d'autres applications et problèmes avec l'expérience acquise.
ETP Statu quo au scénario 4: 9 à l'IRA/CNRC (3 financés par RDDC, 6 financés par le CNRC)

Les versions initiales du thème C comprenaient la fabrication par des techniques biomoléculaires, probablement à cause des possibilités de la biomimétique; toutefois, l'allusion à la biotechnologie dans ce thème a été abandonnée au profit d'un thème D plus solide qui lui est axé sur la biotechnologie. Le thème C est maintenant limité aux seules techniques moléculaires exécutées par l'IRA du CNRC. Les travaux de cette nature sont orientés vers la modélisation des principes de base et la production de matériaux d'essai à l'échelle du laboratoire. La principale application a trait aux revêtements réfractaires pour moteurs d'aéronef; Le programme de FIT de 2001 appuie un tel projet de l'IRA (Zhao : Modélisation des propriétés des superalliages monocristallins).

Thème D (nouveau) : La biotechnologie pour la protection du personnel des FC : Les missions conjoncturelles et de coalition font que le personnel fait face à divers environnements qui présentent une foule de dangers de maladies endémiques et d'autres dangers chimiques et biologiques. La biotechnologie est la technologie habilitante qui permettra l'avancement nécessaire des techniques de traitement, de détection, d'identification et de diagnostic pour assurer la protection de la santé du personnel des FC. La biotechnologie a également des applications en science des matériaux et dans la production de revêtements et de matériaux pouvant améliorer les propriétés de perméabilité, les capacités de filtration et la performance dans les environnements hostiles.
ETP Statu quo au scénario 2 : pas de ressources Scénario 3 : 20 au CRDS Scénario 4: 30 au CRDS

Le thème D témoigne de la nécessité d'un effort de biotechnologie plus classique dans le cadre du programme de RDDC. Il est concentré au CDRS pour être placé près de deux activités « clientes » : Évaluation et détection de la menace chimique, biologique ou radiologique et Médecine opérationnelle. Le thème D fournira une technologie d'appoint pour un certain nombre d'activités actuelles du CRDS : Groupe de détection et d'identification, Groupe de protection du personnel et Groupe de médecine préventive.[6]

La collaboration internationale dans le cadre du thème D aura tendance à être orientée vers la DCB, soit dans le cadre du PCT ou d'un forum bilatéral.

Le thème D exigera un investissement important : le plan de dotation prévoit des laboratoires de biologie supplémentaires et indépendants de niveau 3, pour faire face à la demande accrue et pour permettre un accès continu. Les établissements actuels doivent fermer chaque année pour être réaccrédités; des laboratoires indépendants permettraient d'étaler ces fermetures.

Le thème D constituera un ajout utile aux capacités de RDDC, mais il faudra, en revanche, limiter les avantages éventuels liés aux nouveaux matériaux « conventionnels » à deux secteurs assez restreints, mais dont la dotation serait appropriée pour faciliter un réel avancement de la technologie et une collaboration utile avec les alliés. Les thèmes A et B permettront une collaboration plus efficace au sein du Groupe de MAT du PCT, mais ils ne permettront de réaliser que quelques-unes des possibilités qui s'offrent présentent.

Nethercote, W et Hiltz, J. 2001. Stratégies d'exécution de l'activité Matériaux nouveaux et biotechnologie. DREA TR 2001-161. Centre de recherches pour la défense Atlantique.

[6] Probablement également le Groupe de thérapie médicale

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1. Introduction

At the June 2000 executive retreat of DRDC's R&D Executive Committee (RDEC), Directors General of Defence Research Establishments were assigned the task of developing implementation strategies for several R&D Activities described in the DRDC Technology Investment Strategy (TIS).[1] The DG/DREV was assigned responsibility for Emerging Materials and Bio-Molecular Technologies, one of six 'growth areas' identified in the TIS.[2]

The DG/DREV and his Chief Scientist initiated a program of work, but found they were unable to progress it expeditiously, and so DG/DREA assumed the task. DG/DREA assigned DDG/DREA to the role.[3]

When DG/DREA presented an implementation strategy on the Signatures Activity to the RDEC, he was criticized for divergence from the published TIS. As a result, DG/DREA advised that the present study should address only those foci included within the description of the Emerging Materials and Bio-Molecular Technologies (EM & BMT) published within the TIS, unless strong rationale for departure were presented. See Table 1, overleaf, for the definition of the activity and its three foci.

To restrict the study's scope to the three established foci provided some limit to the problem, but by no means trivialized it. No end of activities could fit within the bounds of the three foci, and so the core of the task became one of identifying the *few* fields which should be addressed in sufficient depth to be robust and useful. But which of the *many* possibilities should be recommended?

In the end, regardless of constraint, the third focus was split to permit a stronger commitment to competency in biotechnology, and the activity was renamed Emerging Materials and Biotechnology (EM & BT), although the original name is used in much of this report.

1.1 Initial Work by DREV

DREV's approach to the problem was to conduct initial consultations with a limited number of agencies (for example, NRC IMI and the Université de Sherbrooke) prior to focussing on development of a contract-based approach with the Centre de Recherches Industrielle de Québec (CRIQ). The proposal formulated by CRIQ was both innovative and promising, but required a financial commitment of the order of $300 thousand, an unrealistic sum in the circumstances.

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[1] Defence R&D Canada, Technology Investment Strategy for the next two decades, (Ottawa: Department of National Defence, undated)

[2] Technology Investment Strategy for the next two decades, p. 24

[3] The Defence Research Establishment Atlantic does not currently have a Chief Scientist and so the DDG represents DREA at TAWG, and was the lead TAWG member for the Emerging Materials and Bio-Molecular Technologies activity Additionally, DDG/DREA is the Canadian representative to TTCP MAT Group

The CRIQ proposal would have involved phased study by experts, together with workshops to assess the experts' contributions, ultimately leading to establishment of a software-based technology watch activity. The goal was a worthwhile one, but beyond the expectation and budget of an implementation plan, which simply envisioned staff work and possible travel expenses, not the establishment of a capability *per se*.

Table 1: Scope of Emerging Materials and Bio-Molecular Technologies Activity[4]

Definition: Identification and development of advanced or novel materials, whether organic or inorganic, for exploitation in military activities. This activity does not include the exploitation of emerging materials or bio-molecular technologies *per se*, since that would be more properly resident in other, application-oriented R&D activities.[5]
Focus A: Functional Materials for Transducers, Actuators, and Smart Structures: The performance of functional materials is a key constraint on performance of transducers (such as sonar projectors) and actuators and signature control devices (such as active machinery mounts). Introduction of functional materials with higher than hitherto strains can have far greater benefit than any amount of ingenuity with transducer geometry and could lead ultimately to the development of structures capable of optimal response to external loads.
Focus B: Substitution of Conventional Materials by Tailored Polymers: Such substitutions demand both careful selection and formulation of materials and re-examination of design parameters so that materials capabilities are exploited optimally. Tailored polymers will require development of advanced modeling techniques for the prediction of mechanical or chemical performance and estimation of feasibility of formulation.
Focus C: Synthesis of Military Materials by Molecular Manufacturing techniques or Through Bio-Molecular Technology promises significant improvements in performance, whether through better protection of personnel (body armour or 'adaptive' clothing ensembles, for example) or more capable structures, sensor, or protective measures for platforms.

1.2 Strategy for Information Collection

Although there appeared to be little prior activity on the EM & BMT activity within DRDC, it was apparent that there was broad interest in it. Consequently, an effort was made to interview staff from all DRE's. DREO advised that a visit to their site was not

[4] <u>Technology Investment Strategy for the next two decades</u>, pp 24-27

[5] The TIS indicated that "As a *modus operandi*, this R&D Activity would at most, conduct technology watch and 'pilot applications' of promising candidate materials, probably at a 'brass board' level, or ultimately through simulation, prior to passing the candidate material over to one of the more application-oriented activities for exploitation " It will be seen that the present study does not take the TIS too literally.

necessary, and the DCIEM main site was not visited, following DCIEM's recommendation that their Air Vehicles Research Section based at NRC's Institute for Aerospace Research would be best prepared to provide input on the matter.

Interviews were also arranged with selected outside agencies, such as RMC, NRC Institutes, or the UK's Defence Evaluation and Research Agency.

Finally, recourse was made to the literature, whether classical or electronic. TTCP and other technology watch activities were particularly valuable.

The results of these investigations are presented in the following ways:

- Section 2, that describes meetings with DND staff
- Section 3, that describes meetings with other agencies
- Section 4, that describes literature review
- Section 5, that discusses biotechnology
- Section 6, that discusses implementation options for Focus A of EM &BT
- Section 7, that discusses implementation options for Focus B of EM &BT
- Section 8, that discusses implementation options for Focus C of EM & BT
- Section 9, that discusses implementation options for Focus D of EM & BT
- Section 10, that provides recommendations; and
- Annex A, that provides a description of the activity after amendments recommended herein.

2. Meetings with DND Scientific Staff

2.1 DREV

At the time of the turnover of the present study, Nethercote met with Dr. Denis Faubert, DG/DREV and Dr. Maurice Laviolette, CSci/DREV, as well as a number of defence scientists. Further discussions were also held at the time of a later visit to DREV by Nethercote.

DG/DREV noted DREV's interest in a number of materials areas: electronic materials, nano-materials, micro-systems, energetic materials, and terminal effects (with particular interest in ceramics). He noted that DREV no longer maintained a materials laboratory, but did have a limited materials characterization capability. He highlighted DREV's successful collaboration with NRC's l'Institut de Recherche en Biotechnologie on bio-remediation of soils following contamination by munitions. In a related initiative, he foresaw the development of biodegradable energetic materials which would ultimately reduce, if not eliminate future requirements for bioremediation. He also noted interest in high-temperature superconductors for electro-optic applications, although such materials were nominally outside the scope of the EM & BMT activity.

One interesting observation was made later by Maurice Laviolette: "DREV should be users rather than developers of materials." He then opined that he could not envision a return to the prior state wherein the DREV organization included a dedicated, classical materials laboratory. His opinion was indirectly supported in later conversations with DREV scientists. When Nethercote reported that the MAT Group had been impressed by the materials-related activities in DREV and that such scientists would be welcomed into the MAT program, the general response was that they preferred to collaborate within the TTCP Weapons Group.

Discussions with scientists engaged in energetic materials research highlighted their view of the importance of nano-materials to their endeavours. New manufacturing technologies would be required to exploit nano-materials, as would facilities for characterization. The Universities McGill and Sherbrooke were noted as strong centres of expertise in emerging materials.[6]

Carbon nanotubes were of considerable interest at DREV and the topic of a TIF project.[7] Potential applications were varied, ranging from hydrogen storage, through structural and electronic applications. Hydro Québec, Université de Québec (both its l'Institut National de la Recherche Scientifique and the Hydrogen Research Institut were considered to be centres of expertise. A program in nano-technology was seen as an important element in advising DND and the CF. Developing Canadian expertise would have broad benefits, particularly when there is no US industrial-scale manufacturer of carbon nanotubes (although there is a US supplier of research quantities of these materials).

DREV's activities in terminal ballistics and human protection are now focused more on modeling than materials development, with materials generally, but not exclusively being ceramics. A notable exception to use of ceramics is the Bio-Steel™ spider silk being investigated by Nexia under DIR sponsorship. The spider silk DIR project was an example of how materials development could be conducted through contract, leaving internal human resources free to concentrate upon application or exploitation, although Nexia's work is not DREV-initiated.

Overall, the weapons-related community provided strong and consistent support for nano-materials when asked "is there one area above all else that we should examine?"[8] There was equal support for emerging materials in the munitions field, although there the interest lay in smart materials for structures and MEMS for actuators for control of weapons, whether missiles or tube-launched rounds. Such applications demand a

[6] The scope of their expertise was not investigated in this study. Université de Sherbrooke has established l'Institut des matériaux et systems intelligents (IMSI) under the leadership of Professor Denis Gingras of the Electrical Engineering Department. A presentation from a member of IMSI at CANSMART 2000 suggested that the institute's interests lay primarily in application of smart systems

[7] "Hydrogen Storage on Carbon Nanotubes and Nanofibers"

[8] Much later than the visit to DREV, Slvain Désilets reported the results of an NRC workshop on Nanotechnology (3772 12nt11 (DREV 3830) 24 January 2001) in which the President of NRC indicated NRC's intention to establish an institute concerned with nano science in Alberta, and encouraged the creation of an Integrated Nano Science Network (INSN).

systems approach to the application, highlighting the need for close cooperation between the materials and applications communities.

It was suggested that the best ROI would arise from directing smart materials and MEMS work towards fluid dynamics and particularly guidance of missiles and control of minature UAVs.

During a subsequent visit to DREV, nanotechnologies was again the topic of discussion, both from the point of view of the Workshop on Storage of Hydrogen in Carbon Nano-tubes (see Section 4) and the nanotechnology position paper being prepared for DST Pol by Jean-François Drolet.

2.2 DCIEM/AVRS

Nethercote held a short meeting with Mr. Ken McRae, Head/AVRS, to introduce the topic of EM & BMT. McRae noted that such work would in fact, be conducted by IAR staff. Indeed, DSTM, AVRS and IAR staff had been engaged in discussions leading to the development of a strategic response by IAR to DRDC's Technology Investment Strategy.[9] The IAR paper, then in draft form, identified five area(s) where IAR felt it could address the TIS:

- Design of Aerospace Materials from First Principles, an activity shared by NRC's IAR and SIMS to extend quantum- and meso-mechanics modeling techniques and apply the resulting computational techniques to aerospace materials possessing controlled microstructures. The focus of the work would be 'design-for-task' tailored materials for extreme environments and smart materials.

- Modeling and Simulation of Material Response to Military Operational Environment(s), entailing creation of material-independent models for damage evolution and growth, as well as models and tools for thermo-mechanical analysis of complex shapes.

- Novel Materials for Multi-Spectral Signature Reduction, to initiate active research in this important field in Canada, to design, characterize and assess the effectiveness of stealth coatings for aircraft and UAVs. Both materials research and measurement techniques would be addressed.[10]

- MEMS for Aerospace Applications, which is self-explanatory.

[9] "Strategic Opportunities in Canadian Forces Air Vehicles Platform Technology," undated draft supplied by H/AVRS

[10] Correspondence to the Nevill/Saville TIF project, "Fabrication of Organic Radar Absorbing material," is noted. See Section 2, DREA/DL(P)

- Nanostructured Coatings and Functional Materials, for which IAR has experimental capability for the creation of materials systems for reduced failure rates and life-cycle costs (high hardness, toughness, low-friction and corrosion resistance).[11]

Further information on the IAR situation and strategy is found later, in a Section describing direct discussions with IAR staff.

2.3 RMC

Nethercote met with Professors Muhkerjee (Physics) and Akhras (Civil Engineering) to discuss opportunities for involvement of RMC in the Emerging materials activity. Prior discussions between DREA staff (Nethercote/Purcell/Hiltz) had developed a mini-APL concept based upon stabilizing and reinforcing RMC's piezoelectric materials characterization capability, which had first been developed under DREA sponsorship.

The preparatory DREA staff discussions had identified 'high-strain functional materials' as one of the key goals of the R&D activity, and recognised the need for a knowledge base of the engineering characteristics of these materials. RMC's expertise in materials characterization was seen as a pipeline between materials developers and applications, if not even as a focal point in a network of excellence in Canadian academia and beyond. An important risk was also identified: the RMC capability had been eroded as DREA financial support declined, and the capability might be lost entirely upon the loss of the key academic staff member, Binu Muhkerjee. Professor Akhras' interests lay in the application of smart materials as sensors or actuators in a smart structures context.

The RMC views corresponded largely with DREA's, identifying the desirability of the maintenance of a materials characterization capability, and extending to development of materials and their application to devices as optional goals. The retirement of Professor Muhkerjee in a five to six year timeframe was seen to threaten existing capability.

A robust model for characterization of functional materials was postulated, as follows:

Resource	**Cost/annum, $K**
RMC Professor (currently Muhkerjee)	In RMC budget
Research Chair (new)	100
Post-doctoral fellow	40
2 x Research associates (EG or MSc)	2 x 50
Operational support	100
Annual Cost[12]	350

Collaboration was identified as a key component of any functional materials program, both with universities and with allies, with TTCP being a particularly important avenue.

[11] Is this an EM & BMT issue, or focus D of the Platform Performance and LCM Activity: "Materials and materials Management for Platform and Systems Safety and Life-Cycle Management?"
[12] EG research associate support may already be available within RMC budget

Finally, possibilities for expanded RMC involvement were also discussed, ranging from the extension of characterization work to include magneto-strictive materials, to the application of functional materials to smart devices or structures.

2.4 DREA/DL(P)

Nethercote met with four of the five Defence Scientists at the Dockyard Laboratory (Pacific), missing only the one currently engaged in research in fracture mechanics of metallic materials, an area outside the scope of EM &BMT, as described in the TIS. The interview approach used in other organizations was potentially problematic at DL(P), where the *raison d'être* for the laboratory is consulting support to MARPAC, albeit in parallel with an R&D program. Indeed, the newest DS at DL(P) is operating under direction to establish his program of research (centered on the TIF project on organic RAM) prior to making heavy commitments to consulting. In practice, this policy does not prejudice delivery of consulting, since technologists are the primary deliverers, with professional support from DS's.

DL(P) conducts a limited program of R&D on marine composites, in part to provide credible access to UK and US technology through TTCP, but the impact of the work is constrained by several realities. First, the scale of work is such that we could not hope to address the scope of leading edge technologies; second, procurement policies, together with the expertise resident in Canadian shipbuilding make the adoption of composites for anything other than minor components or small boats most unlikely. These circumstances suggest that concentration on repair technologies, or in-service characteristics such as fire safety, is most appropriate. The latter characteristic is the greatest impediment to adoption of composites in major combatants. It also is of concern to civil regulatory authorities, which suggests opportunities for dual-use research and possible collaboration with agencies such as NRC. The primary driver in fire safety of composites is the performance of resins, a topic of relevance to focus B of the EM & BMT activity.

DL(P) work in corrosion is driven by life-cycle considerations, and is often faced with re-emergence of old problems. Corporate memory is a rare commodity under the present ship procurement policy regime, in which the current generation of DGMEPM staff and shipbuilders have neither much experience of previous materials lessons nor any incentive to take longer term considerations into account.

One aspect of corrosion management that *is* more than a matter of corporate memory is the contribution of corrosion control systems to ship signatures, where impressed current systems may increase vulnerability to modern ground mines. Is such an issue more properly resident in the 'Signatures' activity, or is it simply a project (thrust) work breakdown element drawing upon EM &BMT and Signatures competency? The latter is probably the case.

The TIF on use of organic materials for RAM is more representative of the sort of innovative, future competency envisioned by the TIS. It is both the focus of DL(P)'s newest DS through the TIF award, and an area of interest at IAR.

2.5 DRES

Nethercote visited DRES with a slightly modified agenda, such that DRES was asked to provide "input that (would) enable a better definition of the bio-molecular aspects of the activity". Overall, there was considerable activity of relevance to EM & BMT in the DRES program and a significant amount of biotechnology activity, most of which was *not* clearly related to the EM & BMT activity as written. The biotechnology efforts were clearly relevant to the Chemical/Biological/Radiological Threat Assessment and Detection and Operational Medicine activities, and offered exciting new possibilities in these nominally 'evolving' areas.

DRES staff were concerned over the degree to which these biotechnology activities were supported by competitive funding from outside the client Service Level Agreement, whether from DARPA, NSERC, Canadian Institutes for Health Research (CIHR), or DRDC's Technology Investment Fund (TIF). Results of TIF projects, for example, were particularly promising to date, but scientists were skeptical of the ability of the R&D Thrust program to exploit the capability established by the TIF projects.[13] In all probability, DRES would be forced to seek ongoing support for these efforts through other competitive programs. This is not problematic *per se*, given DRES' success in such matters but reflects an 'American model' of defence R&D, wherein work generally only progresses with sponsored funding. This concept is orthogonal to the Canadian block-funded technology base model, if not even the TIS itself, and is not supportive of the maintenance of strategic competencies.

Dr. Kent Harding, CSci/DRES, opened the visit with a review of biotechnology and examined its relationship to the EM & BMT activity. He noted that any links were tenuous at best, and raised a number of points:

- That 'materials' were a near-insignificant element of biotechnology, which concentrated more on 'products' and 'processes'
- That technology watch activities were unlikely to succeed in biotechnology
- That DRDC should develop and maintain biotechnology expertise in:
  - Bio-informatics, for medical countermeasures
  - Materials, in EM & BMT
  - In production, in materials and CBR hazards elements and in medical countermeasures; and,
  - In sensors, in medical diagnostics and CBR hazard identification.

[13] As of 30 November 2000, CPME showed the ratio of TIF/TI at DRES in Client Group 6 as 1.1 for FY 00/01, 0 67 for FY 01/02, and 0.59 for FY 02/03. While TIF projects are undoubtedly funded at a more accelerated 'rate' than conventional TI projects, scepticism over the programs' ability to accept, adopt and sustain the competencies established by TIF projects appears justified.

Dr. Harding also proposed consideration of 'some capability' in physical sensors and biomedia relating to electronics, memory storage, neural networks, and nanotechnology.

Dr. Bill Kournikakas, Head/Preventative Medicine Group, described activities in support of Thrust 6qb, Medical Countermeasures Against CB Weapons, noting that the activity is now as much focused against endemic disease as weapons, due to operational patterns. The bulk of the Group's research is now biotechnology-based, and increasing involvement of outside partners has demonstrated that DRES' laboratory facilities are inadequate. The level 3 protection biological laboratories were sized for the Cold War era, but are proving inadequate to support present demands.

Drs. Nagata, Lee and Bader discussed biotechnology products and sensors at DRES and noted that military applications attracted little interest in Canadian industry, without direct sponsorship from (say) DRDC. Biotechnology was now a major focus in chemical and biological defence, and critical to research on new vaccines, anti-virals, gene probes, and antibodies for protection, treatment and diagnostics. Development of recombinant antibodies has been of particular interest at DRES. They particularly noted the important boost that TIF funding had given biotechnology at DRES, and how it had fostered interest in Canadian industry. They warned that lack of biotechnology research in the TIS could squander the advances made through the TIF projects.

The DRES staff made particular note of the need for technology exploitation in biotechnology, holding the view that technology watch alone was not enough. It was only through technology exploitation that DRDC would have the intellectual 'currency'[14] necessary for technology insertion, decision-making, or information exchange with allies. Demonstrated expertise in technology exploitation also served to attract outside sources of revenue, as DRES had so successfully done with DARPA-sponsored work on micro-fluidics, albeit before revenue retention was authorized.

Drs. Tremblay-Lutter and Duncan addressed emerging materials issues in the CB Personal Protection Field, under Thrust 6qd, CB Agent Hazard Avoidance. The focus of their work was a transition to more system-oriented protection, rather than simple assembly of individual components or materials. Their activities will also benefit from TIF support beginning in FY 01/02, under "Nanostructured Metal-Organic polymers for CB Protective Barriers." A Technology Demonstration project has also been proposed.

To date, textile materials limitations have had a significant effect on performance of protective ensembles, a limitation that could be reduced through application of emerging materials, in areas such as: air permeable fabrics; adsorbents; impermeable/semi-permeable membranes; reactive materials; and thickness, weight and durability enhancements. For example, existing ensembles rely upon air permeability to reduce individual heat burden, but are subject to CB vapour penetration that is proportional to wind speed. Novel materials or biomimetics could reduce the effect of this problem. The Personal Protection Group's TIF project aims at addressing the problem through

[14] Currency. [a] commodity used as a medium of exchange; the condition of being current (The Concise Oxford Dictionary, Eight edition, 1990). In this case, both definitions apply!

development of a 'smart' protective polymer membrane having selective sorption of large organic molecules, chemical reactivity, chemical-luminescence for user awareness, and water vapour permeability.

3. Meetings with Other Agencies

3.1 DERA Structural Materials Centre, Farnborough

Nethercote met with Dr. John Morton, Director, Mechanical Sciences and UK National Representative to TTCP MAT Group, Dr. Richard Jones, Technical Director, Mechanical Sciences, and Chairman MAT TP 1, and Dr. George Morris, Assistant Technical Director, Mechanical Services in October 2000. In way of preparation, a copy of the TIS was provided, together with the following guidance:

> ...what you would recommend as fruitful new elements of a program, recognizing that we are probably limited to an increase of at most 25 scientific staff to cover the three new foci. Clearly, we must be selective to avoid being spread unacceptably thin.
>
> You might, or might not wish to make recommendations in the context of what would facilitate collaboration in the MAT Group. Could we consciously identify new activities that would complement those areas that the UK and US have proposed to MAT, but have failed to find support from a third nation?

The meeting began initially with a description of key elements of a report, not available for release, prepared by DERA for the EU on the topic of emerging technologies. The report identified a number of promising or potentially rewarding topics:

- Inorganic/organic hybrid matrix resins that would offer improved fire resistance. These resins would be fabricated through 'growing' inorganics into the polymer chain or through the mixing of nano-composites.

- Cost-effective manufacture and fabrication of titanium, which would enable the exploitation of titanium's desirable materials properties outside the aerospace regime, where premium-priced products are acceptable.

- Silicon-carbide intermetallics for aero-engines

- Thermal barrier coatings for aero-engines

- Hollow glass fibres as damage indicators in damage-tolerant design.[15]

[15] Such fibres would also be particularly suitable for acoustic applications such as sonar domes, providing all of the acoustic performance of Spectra™ reinforcement without suffering from that material's problem of mechanical creep under load

Subsequently, DERA presented a number of topics of importance to them, both nationally and in the TTCP context:

- Nano-materials were first on DERA's 'list', with carbon nanotubes being the most important variant. Ceramers and nanocomposites were seen to offer great promise, subject to overcoming difficulties in synthesis.

- Appliqués were attractive in a broad range of applications, whether related to simple life-cycle concerns (e.g.: corrosion protection) or military function (e.g.: RAM).

- Metallic foams of greater than 90 per cent porosity were seen to offer various benefits, from simple structural stiffness in buckling-driven designs, to multi-functional performance, combining load-carrying ability with, for example, thermal shielding.

- Metallic glasses to emulate the failure characteristics of depleted uranium that make it so effective in long-rod penetrators, and avoid the deficiencies of the next-best choice, tungsten.

- Magnetostrictive materials such as Terfenol™, and doped PZT with phase change for more effective transducers

- High temperature magnetic materials for electric motors

- Nano-crystalline materials which, despite being considered 'old hat' in many quarters, may offer promise in stealth applications

- Large, self-assembling supermolecules that would have shape in their own right and spatially-varying properties, leading to applications such as film appliqués which could be, for example, extremely sticky on one side yet wonderfully slippery – or stealthy – on the other.

In closing the discussions, DERA staff reflected upon the need for some consideration of application in the investigation and development in new materials. Typically, materials developments that neglected considerations of application failed to make the transition to service. 'Solutions looking for problems rarely find homes', a truth which bedevils many strategically-oriented science planners.

While it was not high in the list of pure materials issues *per se*, DERA noted the importance of power sources, both at small scale and as vehicle power sources. For naval applications, the Royal Navy did not accept the concept of methanol reforming, regarding methanol as an 'unsafe fuel.' Instead, they preferred the comfort and safety of naval distillate (Diesel fuel), accepting that it was a far greater challenge to exploit naval distillate as a fuel source for PEM fuel cells. Of course, nano-materials once again enter into consideration as potential storage media for pure hydrogen, the immediate fuel for contemporary PEM fuel cells.

3.2 NRC, Institute for Aerospace Research, Ottawa

Nethercote visited IAR on 1 December 2000, for presentations and discussions with staff. Mr. D.L. Simpson, Director, Structures, Materials and Propulsion Laboratory provided a corporate overview and defined IAR's working relationship with DRDC through the Air Vehicles Research Section. Drs. Jerzy P. Komorowski, Structures Group Leader, and J-P. Immarigeon, Metallic and Ceramic Materials Group Leader, provided details of technical programs. The visit closed with informal discussions with the DG/IAR, Dr. Bill Wallace.

The IAR presentations included a number of overarching themes, one of which was the need to consider the definition of 'emerging materials' in a Canadian context. The IAR view was that "if it hasn't been done in Canada, it's an emerging technology," and examples were provided in justification:

- When the CF-18 entered service, composite repair technology was required, and it had been developed by the USAF, but was embargoed as a critical technology. DREP/Dockyard laboratory undertook the necessary R&D to establish a knowledge base and credible capability in Canada. Technology watch didn't work, because our allies wouldn't let us 'look.'

- The new Cormorant (EH-101) search and rescue helicopter makes considerable, and effective use of Al-Li alloys. There is essentially no expertise in Al-Li alloys in Canada, whether in government or industry. Resident expertise will be necessary to be smart buyers and users of both the aircraft and its servicing, which will be provided through ASD. In-house expertise *per se* cannot be acquired through technology watch, but must be developed, hopefully with the assistance of allies, although such assistance is not always forthcoming as noted previously for the CF-18.

Thus, the essence of the IAR argument is that the definition of emerging materials must be broadened in a Canadian context to include technology insertion into Canadian practice, even where the technology is well-established elsewhere.

IAR also noted the benefits of the synergism between its own research and DRDC, or other sponsored work. The Institute's full spectrum of capabilities, from concept (research), through qualification (FAA-approved certification testing), to life cycle management (the CF-18 fatigue testing, for example), provides context for fundamental work which otherwise would be less likely to find operational application.

The IAR presentations outlined various topics of interest to the TIS:

- Fiber-metal composites, which are in use in the C-17 and proposed for the Airbus 3xx
- Adaptive control of structures

- Retrogression and re-aging of aeronautical structures
- Autoclave process modeling for composite manufacture
- 'Smart patching', and integration of sensors in composites
- Advanced coatings for engine life-cycle extension, or replacement of Cadmium
- The successful TIF proposal by the IAR scientist Zhao: "Modelling of Single Crystal Superalloy Properties from First Principles"
- Functional coatings for signature reduction/management

There were also cases where interaction between the air and maritime communities might be beneficial; these are being explored under other initiatives.[16]

3.3 Acadia Centre for Microstructural Analysis (ACMA), Wolfville, NS

Nethercote attended the official opening of ACMA, 24 November 2000, a facility made possible through support from the Canadian Foundation for Innovation. ACMA operates in conjunction with the Chemistry, Physics and Biology Departments of Acadia University, under the Chairmanship of Dr. Craig Bennett of the Department of Physics. The CFI grant enabled acquisition of imaging instrumentation for materials characterization, failure and fracture analysis, metallography, defect characterization, environmental chemistry and particulate analysis, and organismal, tissue and cell morphological imaging.

3.4 NRC, Biotechnology Research Institute, Montreal (BRI)

On 11 December 2000, Hiltz visited BRI and was hosted by Mr. Adrien Pilon, Director, BRI Environmental Biology Sector. The Institute facilities cover a total of 25,800m^2 and include a 6,300m^2 industrial incubator wing housing 16 companies. In 2000, 820 people worked on site. These included 304 NRC employees, 60 students and post docs, 174 guest workers, 260 employees from private companies, and 22 agency staff. Research and development at BRI is focused on environmental and pharmaceutical biotechnology. This focus is reflected in the activities of its three sectors: Environmental Biotechnology, Pharmaceutical Biotechnology and the Bioprocess Sector.

3.4.1 <u>Environmental Biotechnology</u>

The foci in this sector are bioremediation and sustainable development. Bioremediation involves the use of bioprocesses for pollution control, prevention, and monitoring and the development of new bioprocesses to reduce atmospheric contaminants. Other areas of interest include the use of biotechnology to clean up air borne industrial pollutants, identifying plant/bacteria mixtures for soil remediation, and designing DNA microarrays to identify and monitor bacteria in soils and waste waters.

[16] A visit to IAR by DREA's Group Leader/Structural Acoustics and Strength had been scheduled, but delayed due to injuries incurred in a traffic accident. TTCP AER TP-4, led by IAR staff, has scheduled its March 2001 Annual Meeting at DREA to allow interaction with DREA TTCP MAT Group staff, and DREA structural specialists

3.4.2 Bioprocess Sector

The foci in this sector include the development of innovative bioproducts and processes through the use of recombinant microbial, insect, and mammalian cell cultures. Recent work has been directed at developing microbial 'manufacturing plants' to produce recombinant protein and gene vector products, the use of enzymes to produce anti-viral drugs, and the growth of human cells in serum free culture for the production of adenovirus vectors. The development of monitoring tools and culture methods to promote fast and affordable bioprocesses are other areas of interest.

3.4.3 Pharmaceutical Biotechnology

Research efforts are focused on discovery of drugs for the treatment of cancer and infectious disease. This involves a wide range of activities including the identification of molecular disease targets and the discovery/design of drug lead components. This sector has the facilities to produce customized DNA arrays and a high throughput screening facility for testing large numbers of chemical entities as potential drug candidates.

3.4.4 Interviews

While at BRI, Hiltz met with four scientists, Dr. Denis Rho (Environmental Biotechnology Engineering Group), Dr. Denis Groleau (Microbial and Enzymatic Technology Group), Dr. Charles Greer (Environmental Microbiology Group), and Dr. Jalal Hawari (Environmental Biotechnology). He also met with Ms. Eileen Raymond, the project manager for industrial affairs in the environmental biotechnology sector.

Dr. Rho hosted the visit and tour of BRI's facilities. He was asked to comment on the importance of 15 biotechnology areas proposed in the CytoBio Technics report as important to DRDC. These areas are listed in Table 2, Section 4. He indicated that genomics is the base from which biotechnology will evolve. That is, genomics is the enabling science. Biotechnology will arise from the exploitation of the science. Protein and peptide chemistry, where proteomics will allow the exploitation of the knowledge of genomes to produce materials, was cited as an example. He indicated that genetic engineering was a powerful approach to many problems and that the field was rapidly expanding but that work in this field required laboratories that are suited to the organism being genetically modified.

Vaccines and immunology were also seen as being extremely important. Bioremediation is an area of expertise at BRI. BRI has collaborated with DREV scientists in research directed at remediation of soil and water contaminated with explosives including TNT, RDX, and HDX. The institute also has a program directed at the use of microorganisms to remove volatile organic compounds at industrial sites. When asked about the use of this technology for submarine atmospheres, Dr. Rho indicated that the potential was there.

Microbiology was seen as another enabling science for biotechnology and could include most of the topics on the CytoBio Technics list. For instance, applied microbiology includes the fields of bioconversion (the use of microorganisms to convert materials), biotransformation (use of enzymes to produce fine chemicals), and bioproduction (the use of microorganisms to produce products including biopolymers). Purification/separation techniques can also be grouped under applied microbiology.

BRI has recently purchased a high throughput screening facility to aid in research into the drug activity of compounds. BRI also studies the structure of compounds to aid in the identification of molecular disease targets and the discovery/design of drug lead components. Nuclear magnetic resonance, mass spectrometry, imaging techniques and other analytical techniques are seen as basic tools for structural identification.

Information tools/Computer modelling will allow researchers to take advantage of the huge amount of information made available from genomic research, manage new information, utilize expert systems, and aid in risk assessment of potential biotechnology products.

Dr. Denis Groleau (Group Leader Microbial and Enzymatic Technology Group) suggested that DRDC should concentrate its efforts in four areas; vaccines, detection technologies, environmental monitoring, and advanced materials arising from biotechnology. He noted that he had worked on developing biological pesticides with the US Army.

Dr. Charles Greer conducts research in the area of environmental microbiology. He has been involved in the development of biochips that allow the screening for multiple organisms or compounds. For instance, a biochip could be used to identify the microorganisms in a waste stream or be designed to detect and identify biological agents.

Dr. Jalal Hawari is a chemist in the Environmental Biotechnology Group. His interests are bioremediation, characterization, assessment, and determination of pathways in the bioremediation process. He has been involved with DREV in the remediation of soil and water contaminated with TNT, RDX, and HDX and with CFB Bagotville on assessment studies of nitrate contaminated soil.

Ms. Eileen Raymond is the Project Manager, Industrial Affairs for the Environmental Biotechnology Sector. She explained that her responsibilities include facilitating contracting and collaborative efforts with outside agencies, universities and private companies. She recommended that another meeting be convened between BRI and DRDC to explore areas of common interest and potential collaboration.[17]

[17] Were such a meeting to be held, DRES would be able to provide the most appropriate DRDC representation

3.5 NRC, Industrial Materials Institute, Boucherville (IMI)

On 12 December 2000, Hiltz visited IMI and was hosted by Mr. Nafez Melhem, IMI Marketing Manager. Mr. Melhem gave an overview of IMI. The institute has 150 staff, 125 of which are scientists, engineers and technical officers, and a number of visiting researchers and students. IMI is an integrated technology center and has multidisciplinary expertise in the modelling, optimization, development and control of material processing. Materials of interest include metals, polymers, ceramics, and their composites and alloys.

While at IMI, Hiltz met with Drs. Champagne, Sabsabi, Monchalin, Dumolin, Pelletier, Denault, Marple, and Hetu.

Dr. Champagne's interests are in the optimization of the properties of polymeric materials, including films and foams, through control of the production process. Processing facilities include equipment to produce multi-layered films, injection, extrusion and blow molding equipment, and a biaxial stretching apparatus to produce oriented polymer films. Dr. Champagne is also interested in rheology of polymers and polymers melts, in particular how melt viscosity affects the foam production process.

Dr. Sabsabi's interests are in process instrumentation. He demonstrated a technique for the real time analysis of industrial materials composition. The technique uses plasma laser spectroscopy and requires no contact with the sample, is independent of the physical state of the material, and requires no sample preparation. Dr. Monchalin is developing laser ultrasonic technology that can be used to measure thickness of materials, detect and image flaws in complex structures, and characterize material microstructure. As this is an optical technique it can be used at considerable stand off distances from the structure being studied. He stated that work in his group had a number of potential DND applications in the areas of sensors, chemical biological defence and explosives research. Specifically he mentioned work with DRDC-IAR on detecting corrosion in aircraft structures and with DREV on the use of ultrasonics to detect cracks in rocket propellants.

Dr. Pelletier's interests are in the area of powder metallurgy, porous metals, and the development of processes such as net shape forming to reduce the costs of metallic material. Process facilities include sintering furnaces, a 100-ton hydraulic press for compaction studies, a cold 25-ton isostatic press, and a 150-ton press with heating for warm compaction.

Dr. Denault's interests include the development of microstructure in thermoset composites to avoid failure, E-beam cure of resins to minimize residual stresses in fabricated composites, and development of continuous fibre reinforced thermoplastic composites. She sees several advantages to fibre reinforced thermoplastic composites including increased toughness, less water absorption/water loss, and the ability to recycle waste. Prepreg thermoplastic composites can be processed in a number of ways including compression molding, thermoforming stamping and roll forming. From a research perspective she is interested in studying the polymer fibre interphase and its effect on fatigue and impact properties and the fracture mechanisms.

Dr. Marple's interests are in the area coatings specifically as they apply to corrosion and erosion corrosion abatement, and thermal barrier materials. He uses thermal spray of metal powders or wires and plasma spray of ceramics to produce cermats.

Dr. Hetu's interests are in the area of process modeling and optimization. The software was developed at IMI and has been used for 3D modeling of the injection molding process. He plans to model at a 'smaller' level, that is, meso rather than macro, in the near future.

Discussions with Dr. Dumolin, the Director of the Materials and Processes Section, indicated that IMI is in the process of developing a strategic plan for the next several years. He suggested that one of their strategies would be to become more involved with new materials. In the recent past IMI had concentrated on optimizing processing conditions to develop material properties. He also indicated that polymer modeling, as opposed to process modeling, was an area where there is very little effort in Canada.

4. Literature Review

4.1 CANSMART

The Canadian SMART Materials and Structures Group (CANSMART) was formed to promote research and development of smart materials and structures technologies for applications in engineering. CANSMART's detailed aims are to:

- Promote the research, development and use of smart materials and structures in all possible applications in Canada;
- Regroup all the interested persons in the field from Industry, Consultants, Government, and Universities;
- Facilitate the acquisition and interchange of technical knowledge among its members;
- Establish contact groups for possible collaboration to promote smart materials and structures;
- Organize meetings, workshops, conferences on smart materials and structures.

Nethercote is DRDC's representative to the CANSMART Board.

The Third CANSMART Workshop was held at the Canadian Space Agency, St. Hubert, 28-29 September 2000.[18] DREA was represented by Nethercote and Drs. C. Purcell and S. Nevill, who presented papers. Eighteen papers were presented, with the majority being focused on topics related to the use of functional materials in structural, actuator, or transducer applications. In some respects, the papers were most notable for the variety of Canadian agencies in the authors list:

[18] George Akhras, ed., Proceedings of the 3rd CanSmart Group Workshop on Smart Materials and Structures, (Kingston, RMC Civil Engineering Department, September 28-29, 2000) ISBN 0-9685840-1-2

- DREA
- McGill University
- University of Victoria
- Royal Military College
- Sensor Technology Limited
- Université Laval
- Université de Sherbrooke
- McMaster University
- University of Waterloo
- University of Toronto
- Canadian Space Agency
- Dalhousie University
- Coupled Systems Limited

4.2 Workshop on Carbon Nano-tube Hydrogen Storage

Dr. Sylvain Désilet of DREV made a successful application for DRDC TIF support for a project, "Hydrogen Storage on Carbon Nanotubes and Nanofibers." After the award, Dr. Désilet organized a Workshop on the storage of hydrogen on carbon nanostructured materials. The workshop was designed both to stimulate interest in the topic and facilitate collaboration among Canadian researchers in the field. There were 13 presentations, followed by a round-table discussion in the workshop. Thirty-two attendees represented 16 organizations.

NRC's Stacie Institute and the Université de Québec's Hydrogen Research Institute appear to be in the forefront of application of carbon nanomaterials to hydrogen storage, although the many other players are doing scientific work no less advanced. It is evident that opportunities exist to create a network of excellence on the topic.

4.3 DRDC Contracted Study of Biotechnology in Canada[19]

DRDC, realizing that biotechnology is increasingly important in a number of areas of interest to National Defence, initiated a study aimed at defining how DRDC might best exploit advances in the biotechnology field for the benefit of the Department of National Defence and the Canadian Forces. The study included overviews of the Canadian and International Biotechnology industries, a review of intellectual property rights (patent law and biotechnology and current intellectual property issues), reviews of the stages in the development of biotechnology products and biotechnology trends, and an overview of DRDC's R&D strategy. A summary of this report follows.

[19] CytoBioTechnics Inc, "Development of a Long-Term Biotechnology Strategy for Defence Research and Development Canada," (Oakville, Ontario, PWGSC Contract Number W7714-9-0303/001/SV, March 2000)

4.3.1. Canadian Biotechnology Industry

The Canadian biotechnology sector includes over 500 firms employing in excess of 25,000 persons. In 1997 expenditures on biotechnology research and development was over $750 million. The largest expenditure was from industry ($340 million), followed by government laboratories and granting agencies ($304 million) and private not-for-profit organizations ($115 million).

Sales related to products and services in the biotechnology area were approximately $800 million in 1996. The major contributors were the human biologicals and diagnostics ($396 million), agri-food ($319 million), aquaculture ($59 million) and environmental ($38 million) sectors.

A 1997 survey indicated Canada had 224 core biotechnology firms of which 72 per cent had less than 50 employees. Capital financing amounted to $2 billion for the period 1991-1996. The report noted that this level of financing was barely enough to complete the development of targeted products where costs range up to $250 million per product. The ability of the Canadian biotechnology innovation sector to transfer technology and commercialize products is improving. In 1996, 100 biotechnology and life science products were in pre-clinical or clinical trials. However, the system still lacks competitive strength and many Canadian firms lack technology evaluation and transfer expertise.

Federal funding of biotechnology in Canada lags behind that in the USA, Germany, the European Union, and Japan. There is a need for the development of relationships between firms, institutions and organizations and links to financial institutions and venture capitalists. The MRC and NSERC efforts in this area are promising. IRAP, for instance, connects firms to technical advice and research institutions across Canada.

Future biotechnology innovation will require the ability to manipulate tremendous amounts of data and resources. The biotechnology community will need databases and data networks that will allow this flow of information.

4.3.2 The International Biotechnology Industry

The US dominates the international biotechnology industry and the majority of the US industry is located in specially formed firms. The domination is attributed to a strong university and scientific research base in the US and the industrial capacity to convert basic research into products. US government support, the entrepreneurial culture, a favourable science-based regulatory structure, intellectual property policies, incentives for research in otherwise unprofitable areas (Orphan Drug Act), ease of Stock Exchange listing and a large number of venture capital firms are all cited as reasons for this prominence.

In the rest of the world new biotechnology companies do not dominate. Research has been concentrated in large pharmaceutical companies (Glaxo, Hoffmann-LaRoche), chemical companies (Novartis), universities and research institutions (Institute Pasteur). Some dedicated firms are starting to participate, especially in the UK.

The biotechnology industry continues to experience major losses. These are due to R&D costs and the time associated with marketable products. For instance, it is estimated that it costs $20 million and from 2 to 5 years to bring a new diagnostic product to market and between $150 and $250 million and from 8 to 12 years to bring a new drug or crop variety to market. This has led to alliances between large multinationals to reduce costs and reduce risks. In 1995, the US pharmaceutical industry replaced the stock market as the major source of funding for the biotechnology industry. The regulatory environment is another factor affecting the profitability of biotechnology companies. The approval process for new products varies from country to country and there is no formal mechanism under NAFTA or the WHO for mutual acceptance of regulatory approvals.[20]

The four major sectors of the international biotechnology industry are the biological, pharmaceutical, environmental and chemical sectors.

The biological sector includes the agri-food, in-vitro diagnostic, and aquaculture sectors. The strongest growth is predicted for the agri-food sector. Growth in the in-vitro diagnostic sector is expected to around 10 per cent a year over the next five years. However, growth is expected to be 15 per cent a year in areas such as tumor markers, infectious diseases, cardiac markers, autoimmunity tests, and genetic disorders. The aquaculture sector is still in its formative stages.

Pharmaceuticals hold a dominant share of the market in international biotechnology but growth is predicted to slow to three per cent a year. There are less than 20 biotechnology-based drugs on the market and six of these, account for 80 per cent of revenues. Another 300 biotherapeutics are in various stages of clinical development. These represent 30 per cent of the new drugs under development.

In the environmental sector, bioremediation of hazardous wastes is the fastest growing sector. Commercial applications of this technology rely on the use of multiple strains of naturally occurring organisms to eliminate hazardous compounds. The use of plants (phytoremediation) to eliminate hazardous materials is a growing area. Genetically engineered organisms with special bioremediation applications have not been used to a great extent due to concerns about their effects on ecosystems.

The production of chemicals and fuels through biotechnology is not cost competitive with traditional processes. The most successful application has been in the production of industrial enzymes using fermentation. Active research in this area is focused on improving functional characteristics of enzymes, finding novel applications, and new enzymes for new applications. Microorganisms have been used for mineral leaching and metal concentration but are not cost competitive with traditional methods.

[20] At first glance this is not a national defence, or even national security issue, but regulatory approval processes focus interests on commercially attractive products, rather than those of importance to defence, but perhaps less so to the civil market in the developed world.

4.3.3 Intellectual Property Rights

The report contains a review of the process of intellectual property (IP) protection for the biotechnology industry. This includes defining what a patent is, the Canadian patent application and approval processes, and international patent protection.

Canada is a member of the World Intellectual Property Organization (WIPO), which promotes protection of intellectual property internationally through cooperation among member states. WIPO has convened a working group on biotechnology that will study topics such as legal standards related to scope and character of patent protection, licensing of IP, administrative and procedural issues related to examination of patent applications, the relationship between patents and other forms of IP, and the relationship between patent systems and the moral and ethical issues arising from genetic modifications of plants and animals.

The report makes several recommendations concerning how DRDC should approach the issue of IP rights. These include applying for provisional patent applications. A provisional patent application requires less supporting data than a non-provisional patent and gives the applicant up to 12 months to file a non-provisional patent application. The report also recommends the adoption of standard operating procedures with respect to how experimental data is recorded in laboratory notebooks, filing a patent application with the US Patent and Trademark Office, and follow up with the Patent Cooperation Treaty organization process to broaden patent protection.

4.3.4 Development of Biotechnology Products

The major barriers to biotechnology programs are lack of capital to protect IP and implement a strong patent strategy and failure to ensure the confidentially of inventions. In Canada, the disclosure of an invention before there is a patent application will nullify any claim to IP. From DRDC's perspective, failure to protect IP will result in failure to partner with firms that can exploit the in-house research. It is also very important that scientists understand the importance of the protection of IP. This will require protecting IP prior to publishing.

Patent searches prior to starting a research program are essential to prevent duplicating research and wasting resources. The cost involved in commercialization of many biotech products will require that DRDC partner with industry. The selection of an industrial partner should involve a thorough investigation of the financial position and managerial strengths of the partner.

4.3.5 Canadian Biotechnology Directions

The results of a 1995-1996 survey of the Canadian biotechnology industry indicated that 15 per cent of their effort (as measured by R&D expenditures) was focused on DNA based techniques, 6 per cent on biochemistry, immunology, and micro-organisms, and 20 per cent on using micro-organisms or enzymes to modify processes and process substances or in the development of techniques to analyze or separate products of these processes.

The most advanced technical capability in Canada was in drug design/delivery/pharmacogenetics (32 per cent) and antigens/vaccines (23 per cent). Genetic engineering (11 per cent), genetic engineering applied to micro-organisms, plants, animals, bio-processing/bio-transformation (5 per cent) and bio-remediation (4 per cent) were other areas where Canada has significant capability.

A 1998 survey was described, indicating that genomics, genetic engineering, peptide and protein engineering, antigens/vaccines/immunology, and bio-remediation were the fields that Canadian experts predicted would be the most important areas of biotechnology over the next 10 to 15 years. Following these areas were microbiology, molecular drug design, drug delivery, fermentation/bio-processing/bio-transformation, and molecular signaling/molecular interactions. Other areas mentioned were information tools (bio-informatics, information management, risk assessment), measurement tools, computer modeling, natural products chemistry, functional foods/nutraceuticals, molecular pharming, and purification/separation techniques. These fields, DRDC's present effort and the desired future efforts (as seen by CytoBio Technics Inc.) are shown in Table 2.

4.3.6 Overview of the DRDC Research Strategy

Three Establishments, DCIEM, DRES, and DREO, have thrusts with biotechnology components. Work units in these thrusts include Soldier Systems, Future Helmet Mounted System, Integrated Protective Clothing, Combat Casualty Care, Operational Health Hazards, Military Operational Medicine, Defence Against Chemical, Biological, and Radiological Hazards, Vaccine Development Initiative, Medical Countermeasures, CIBADS, and CB Agent Hazard Avoidance.

The review suggests several areas where DRDC could develop products using biotechnology. This includes CIBADS, vaccine development initiatives, medical countermeasures, military operational medicine, combat casualty care, operational health hazards, and integrated protective clothing.

4.3.7 Contractors' Recommendations Concerning Exploitation of Biotechnology

The report recommends a series of actions that DRDC should take to fully exploit opportunities arising from R&D programs using biotechnology. These are listed below.

1. Complete a detailed customer needs analysis. The analysis should be viewed from the customer's perspective with respect to features and benefits of the product's specifications. Once the analysis is completed the specifications will form the basis of the research and patent/intellectual property plan. The customer will sign the plan upon acceptance of the product specifications.

2. Develop a DRDC strategic research and development plan. The plan should be reviewed on an annual basis and include a short term (5 year) and long-term (10 year) research and development program. The short-term plan should focus on strategies for the completion of technology demonstrators and CF support activities while the long-term plan should focus on future research activities and market trends.
3. Establish a strong link between the BDO, scientists and customers. The involvement of the BDO in projects at the earliest possible stage will strengthen their ability to target market opportunities and increase the licensing opportunities.
4. Develop a patent strategy. A patent strategy should be developed early in the research process to protect intellectual property and allow aggressive licensing programs.
5. Have an internal project/product approval process in place. Someone, for instance the Chief Scientist, must be responsible to ensure the overall performance of the project. This would include ensuring that the project meets DRDC/NDHQ requirements for research, customer requirements and costing.
6. Establish a Methods Development and Transfer Team (MDTT). This team will validate the results of basic research and ensure that a third party can replicate projects. This team should prepare standard operating procedures (SOPs) that will facilitate technology transfer by standardizing methodologies and procedures. When technology is transferred to Industry the SOPs will be an integral part of the transfer. This approach will ensure that good laboratory practices are implemented and followed at the DREs.

Table 2: CytoBio Technics Assessment of Bio-technology Research Fields

DRDC's Activity Level	Research Fields	Desired Future Direction
Modest	1. **Genomics:** This is understood to include bio-informatics, pharmaco-genetics, genetic epidemiology, sequencing and amplification, functional genomics and archiving/coordination of genomic information.	More
Modest	2 **Genetic engineering:** This is understood to include at least the following: gene expression, gene insertion, gene therapy, transgenics, germ line therapy, plant and animal modeling, designer crops, metabolic genetics.	More
Minimal	3 **Peptide and protein engineering:** This is understood to include proteomics, protein-protein interactions, and protein chemistry	Aggressive
Modest	4. **Vaccines & immunology**	Aggressive
Modest	5. **Bio-remediation:** This is understood to include eco-toxicology, environmental biology and designer environmental remediations.	More
Modest	6. **Microbiology:** This is understood to include virology, and enzymology.	More
Minimal	7 **Molecular drug design:** This is understood to include high through-put drug screening.	Aggressive
Modest	8. **Drug delivery:** This is understood to include delivery of biologics.	Aggressive
Minimal	9. **Fermentation/bio-processing/bio-transformation**	Maintain
Growth Area	10. **Molecular signaling/molecular interactions:** This is understood to include cell signaling and cell receptors.	More
Potential Growth Area	11. **Information tools/Computer modeling:** This is understood to include bio-informatics, data mining, information management, expert systems, risk assessment, applied mathematics, meta-genetics.	More
Growth Area	12. **Measurement tools:** This is understood to include mass spectroscopy, imaging, and other analytic techniques.	Aggressive
No Involvement	13. **Natural products chemistry:** This is understood to include organic and analytic chemistry as well as combinatorial chemistry.	To Be Determined
Growth Area	14. **Nutraceuticals/functional foods**	More
No Involvement	15 **Purification/separation**	Aggressive

7. Review the requirements for human and capital resources. To be successful, the DREs must have the skilled persons and equipment to carry out a research program. This will require an analysis of human and capital resources prior to initiating a program.
8. Ensure early review and support for regulatory affairs. The nature of biotechnology requires that all projects go through an early stage review to determine what regulations exist with respect to the research. Failure to determine the applicable regulations could result in the requirement to repeat the research wasting time and money.
9. Development of SOPs for DRDC R&D activities. This would allow transfer/sharing of information between DREs and facilitate transfer of technology to industry. Standardization becomes important when collaboration takes place. Exchange of SOPs enables that there be a continuation of experimental results generated by the collaborators.

4.4 SRI Consulting Technology Map on Smart Materials

Smart Materials is one of the 'Technology Maps' provided by SRI Consulting under its 'Explorer – Business Opportunities in Technology Commercialization Service'.[21] The title of the service is revealing of the nature of the product, being more of a forecast of commercial opportunity than a technology watch at the scientific level. Nonetheless, there are elements of the document relevant to the EM & BMT study.

Of particular relevance is the forecast of commercialization, which examines:

- Electrorheological and magnetorheological fluids and components;
- Magnetorestrictive materials;
- Piezoelectric polymer components;
- Magnetic fluid material and devices; and,
- Shape-memory alloy material and components.

The market forecast for 2009 indicates that magnetostrictive materials will have the least market share of the group by far, a situation that suggests defence support might be required to support defence applications, such as transducers. Technology for other smart materials, and particularly shape memory alloys, is likely to be driven by COTS applications, given the scale of the forecast business volume. A further concern is that growing exploitation of conventional COTS technologies will further reduce their price, delaying the competitiveness of smart materials even more.
Electroactive polymers are likely to be important materials in the future, offering displacements as much as two orders of magnitude larger than piezo-ceramics (up to 30, vice 0.1 per cent strain), albeit with a much lesser force-generation capability.

[21] Nancy I Gaston Festa, Technology Analyst, Technology Map – Smart Materials, (Menlo Park, CA: SRI Consulting, Explorer, Business Opportunities in Technology Commercialization, 2000)

The growth of use of Smart Materials suffers a number of constraints, with the first being the need for overall product design rather than simple component substitution. Additionally, many Smart Materials have not been fully characterised, a situation, together with scarcity of design modeling capability, that discourages introduction of Smart Materials in COTS products.

Returning to magnetostrictive materials, and particularly Terfenol D, there is a need for better characterization and better understanding of applications issues. Development of composite magnetostrictives might go a long way to addressing present applications difficulties. In this respect, DREA's working relationship with ETREMA Products could lead to an alliance that would be of significant benefit to DRDC's transducer development efforts in support of underwater sensing. Applications to SMART aerospace structures might also evolve.

Smart glasses are beginning to see commercial application in the automotive industry (self-dimming mirrors) and have been investigated for use in anti-laser protective goggles for military use. Further development is required to improve response time in military applications. The automotive industry's *commercial* lead in application of smart glasses is likely to be duplicated in other smart materials technologies; broad military application may be constrained to following automotive use through simple commercial considerations.

Notwithstanding commercial considerations, there is still need for materials research: to improve response times; to increase strain of piezo ceramics; or to increase actuation pressure of electroactive polymers.

A most promising opportunity for Smart Materials is in their application to non-intrusive or even in-service non-destructive evaluation. In this case, smart materials might be employed in the structure itself, or as part of a coating which was both protective of the structure and a detector of loading conditions.

4.5 SRI Consulting Technology Map on Biopolymers[22]

Biopolymers are defined as polymers produced by biological systems. Naturally occurring biopolymers include chitin, agar, guar gum, latex, collagen and carrageenan. The unique functional properties of biopolymers has resulted in their use as stabilizers, thickeners, gellants, binders, dispersants, lubricants, adhesives, and drug delivery agents. The uniqueness of these polymers arises from the fact that chemists have difficulty reproducing them cost effectively or in large quantities.
Commercial uses of biopolymers include plastic waste reduction, improved oil extraction technologies, as food additives or foods with lower fat or calorie contents, and in improved drug delivery systems. A major advantage of biopolymers over synthetic

[22] Donna Evans, Technology Analyst, Technology Map – Biopolymers, (Menlo Park, CA: SRI Consulting, Explorer, Business Opportunities in Technology Commercialization, 2000).

polymers is that they are "natural" products and therefore may require minimal regulatory review.

An emerging area in biopolymer research is the use of biopolymers in the synthesis of new materials. Biopolymers are playing key roles in nanotechnology and biomimetic materials synthesis. The unique chemical and physical properties are being used as the framework from which molecular machines and manufacturing are developing. Novel biopolymer architectures, such as lipid tubules and protein lattices, may result in specialized market opportunities.

At this time there are no commodity type markets for biopolymers. Synthetic polymers are still cheaper although advances in fermentation and purification technologies and cheap natural feedstocks may eventually lead to a greater use of biopolymers. The commercialization of transgenic plants that produce biopolymers would greatly reduce costs associated with fermentation and promote increased use of biopolymers. Advances in microbiology, genetic engineering, biochemistry and cell free synthesis are seen as enabling tools for the development of improved and unique biopolymers.

4.5.1 Processes

The ability to modify function to meet customer needs is a requirement for biopolymer manufacturers. This can be as simple as mixing two biopolymers to obtain a blend with the appropriate functional qualities. Chemical and physical processes can also be used to modify function. For instance, chitin can be deacylated to form chitosan, wood pulp hydrolysed to form microcrystalline cellulose, or evaporation or cross linking of alginates used to form films. Newer techniques such as genetic engineering can be used to produce mutants that produce modified biopolymers, for instance xanthan forming bacteria that produce modified xanthans. Synthesis of a short segment of DNA (encoded for the production of a short amino acid repeat segment) followed by enzymatic polymerization can be used to produce a biosynthetic protein. Collagen and gelatin are being produced by genetic engineering of yeast. Cellulose, starch and hyaluronic acid are candidate biopolymers for synthesis by cell free enzymatic methods.

4.5.2 Areas to Monitor

Combinatorial biopolymer design: Combinatorial methods are used extensively by the pharmaceutical industry to pursue new drugs. More recently combinatorial methods have been investigated by the materials community as a route to the rapid development of novel materials. This approach may be applicable to the design of novel biopolymers.

Biodegradable Polymers: In niche markets environmental/biodegradability may be of key importance. These properties would become critical if environmental/biodegradability were legislated.
Advances in Drug Delivery: Biopolymers are frequency used in drug (especially protein drug) delivery systems to control the release of the drug and reduce the number of injections required to maintain the drug at its therapeutic level. Approaches include the

use of biopolymer microspheres and biopolymer gels to carry and subsequently release the drug.

Advances in Tissue Engineering: Biopolymers are used as an adjunct to tissue engineering and as replacement materials. For instance, cartilage has been grown on a biopolymer substrate and recombinant collagen has been used in a number of medical applications.

Genetically Modified Organisms (GMOs): Research may lead to the production of commercially viable biopolymers from GMOs. Initial research has focused on microorganisms and their use in fermentation systems. However, genetically engineered or modified plants are the focus of research to produce materials for in vitro synthesis.

4.5.3 Applications

The textile, paper, and food processing industries are the traditional users of biopolymers. However, more recently the unique functional properties of these materials have led to their use in other applications including pharmaceutics, enhanced oil recovery and cosmetics. Some of the newer applications are discussed below.

4.5.4 Biomedicine

Vaccine Adjuvants: The use of biopolymers as vaccine adjuvants is an active area of research. Adjuvants are substances added to a compound to increase its effectiveness. Some vaccines developed from biological compounds using genetic engineering do not stimulate an immune response when administered alone. Biopolymers appear to be ideal materials for use as adjuvants. Polylactic acid, gelatin and starch are under investigation for their adjuvant properties. These materials are well suited for this application as they allow incorporation of the antigen into the polymer matrix. The resulting slow release of antigen results in a booster effect.

Drug Delivery: Biopolymers are finding increased use in drug delivery applications because they are biodegradable and have been used successfully in other medical applications. In addition biopolymers show promise for delivery of drugs where conventional methods do not offer the stability, bioavailability and efficacy required for the drug. A number of biopolymers, including polylactide and its copolymers, collagen, human serum albumin, and gelatin, are under investigation for use in drug delivery systems.

Wound Healing Agents: Biopolymers, in addition to their use as adhesives, sutures and coatings for wounds, have also been found to speed the healing process. Commercial products include a chitin sheet for use as artificial skin and repair bandage, a collagen sheet covered with fibrinogen, thrombin, and aprotinin for stopping bleeding during surgery, alginate based dressings containing antibacterials, and antiadhesion materials to prevent postsurgical adhesions.

Tissue Sealants and Tissue Engineering: Biopolymer based tissue sealants are under development. One combines spider silk protein with fibrinogen and the other collagen with fibrinogen and other biopolymers. Biopolymers encourage cell growth and have been used for transplanting cell grafts for regeneration of tissue damaged by trauma or disease. They have been used to repair cartilage damage and skin grafting for burn patients. Other biomedical applications of biopolymers include the development of carbohydrate vaccines, in ophthalmic surgery, in prostheses and coatings, in orthopedic repair, in osteoarthritis treatment, vascular implants, and antibacterials.

Cell Culture Adjuvant: A major limitation to the development of biotechnology is the inability to produce products on a large scale. In many instances this is the result of the difficulty of growing mammalian cell cultures outside the living mammal. Research indicates that biopolymers can mimic the natural environment and therefore increase the efficiency and productivity of cell cultures. Advances in large-scale production will increase production of monoclonal antibodies and protein pharmaceuticals. Biopolymers have found applications in the production of single cells with intact cell walls and are useful to immobilize cells, enzymes, and antibodies for use in sensors and purification and separation columns.

4.5.5 Industrial Applications

Xanthan has been the most widely used biopolymer for enhanced oil recovery. Biopolymer use in enhanced oil recovery has been limited by low oil prices, biodegradability and biopolymer cost.

Fusion proteins that combine biopolymer-binding proteins with high value enzymes or therapeutic proteins are being developed to allow the use of inexpensive biopolymers such as starch or cellulose to separate high value proteins from solution.

Research at Sandia National Laboratory is attempting to mimic the structure of seashell, a natural biopolymer. Surfactants are used to facilitate the deposition of alternating layers of organic and inorganic components. Low temperature heat treatment polymerizes the layers and forms a multilayer ceramic material. A potential application of this technology is in the formation of abrasion resistant coatings.

Cornstarch modified by grafting with polyorganosiloxanes is under investigation as a coating material. Testing of the coating containing a corrosion inhibitor indicates that it performs as well as traditional aircraft paints and is 50 per cent less expensive than petroleum derived coatings.

Biopolymers continued to be developed as membrane materials for industrial separation processes. Chitin and its derivatives form the focus of much of the research because of their strength, chemical resistance, and unique charge properties. Potential applications include desalination of water by reverse osmosis, removal of wastes from water and chemical concentration.

Synthetic spider silk is an area of active research. Problems with extracting the insoluble proteins from cells led to the use of transgenic goats that produce a water-soluble silk protein in their milk.

4.5.6 Constraints

Basic research to isolate and characterize the genetic sequence of biopolymers is required to more fully take advantage of their diverse properties.

Large-scale production of second-generation biopolymers made from recombinant microorganisms can be difficult and costly and requires advances in process technology.

No international consensus on regulation of the commercialization of genetically modified organisms exists. The debate surrounding this issue could have a negative affect on the development of biopolymers using this technology.

The purity and availability of natural biopolymers are not constant. Fermentation methods can produce supplies of some but cost may be prohibitive.

5. Biotechnology

Biotechnology is a pervasive element of North American society today, but an element that is under-represented in the DRDC program. This under-representation is not problematic in most instances, where penetration of biotechnology into military operations awaits advances in basic sciences; however, there are cases where failure to address biotechnology will limit operational effectiveness of the CF.

The pervasiveness of biotechnology does not imply that it will overwhelm all in the foreseeable future, for like other technologies, the advance of biotechnology is usually fuelled by commercial opportunity. In principle, bio-polymers are very attractive and could have wide application, but world oil prices might need to rise by an order of magnitude before bio-polymers were competitive in price with petroleum-based polymers. Of course, industrial-scale bio-polymer production would greatly reduce costs, but achieving such production scales is a classic chicken and egg problem.

The R&D Executive Committee of DRDC characterized the Chemical/Biological/Radiological Threat Assessment and Detection and Operational Medicine activities as members of the ‘evolving’ group, probably in response to the end of the Cold War. While the Cold War’s demise has indeed reduced the probability of chemical/biological warfare on the plains of Europe, it has seen an increase in risk of exposure of CF personnel to chemical, and particularly biological threats. That these threats now are as often as not endemic diseases in the third world rather than weapons offers no reduction in threat, when the developed-world pharmaceutical companies see no commercial merit in developing responses to them. Additionally, it has become distressingly apparent that formulation or manufacture of chemical or biological agents is no longer the sole preserve of the major military powers. Third world environments exacerbate the problem through subjecting CF members to heat stress not envisioned when protective ensembles were developed for the Cold War, European battlefield.

The descriptions of the Chemical/Biological/Radiological Threat Assessment and Detection and Operational Medicine activities in the TIS do indicate the importance of biotechnology in the focus descriptions, but the importance of biotechnology is not evident at the focus title level, which is the practical limit of penetration of most client- or executive-readers. It is also not evident how these activities might transition towards new technologies.

DRES staff did suggest the growth necessary to exploit emerging materials and biotechnology. Biotechnology is particularly applicable to Preventative Medicine activities, if not even essential their future survival. Current programs are delivered with five professional and eight support staff. It was suggested that the future establishment should be larger, as follows:

- 6-10 scientists
- 6-10 technologists
- 2-4 military (MAO/Bio)
- 1 facilities engineer
- 2 general support

Additionally, DRES staff noted a current need for more infrastructure, and particularly additional, independent level 3 biological laboratories. In present circumstances, one of two suites is generally unavailable due to revenue generation or contractor work, and both suites are unavailable in summer months due to annual re-certification activities. Additional, independent suites would ensure that such facilities were available throughout the year to respond to operational emergencies, and to provide capacity for program growth. Corresponding expansion of level 2 laboratories would also be required. It would also be beneficial to have a Cobalt 60 source on site for preparation of 'inactive' samples of hazardous materials.

Research in personal protection at DRES might be seen to be less dependent on biotechnology than is Operational Medicine, but biotechnology is no less important as a threat. Indeed, the threat is such that some form of 'smart garment' would likely be required in defence, and such clothing would more likely be successful were it to exploit biotechnology itself, rather than even advanced variants of traditional organic materials, such as carbon nanostructures.

6. Implementation Options for Focus A, Functional Materials for Transducers, Actuators and Smart Structures

There are already a number of established or nascent pockets of functional material expertise within the DRDC community, but not all are purely EM & BMT activities. Many are EM & BMT *exploitation* activities, within other R&D activities, although there is a history of functional materials research, principally related to modeling of transducer driver materials.

At DREA, the long-established focus for application of functional materials has been sonar transducers, with related R&D being performed by the DREA Transducer Group. The Group has long had a working relationship with RMC, and more recently relationships with DREA's Dockyard Laboratory (Atlantic) and Etrema, an American company managing the IP for the magnetostrictive material, Terfenol, and Sensor Technology, a Canadian company holding IP on piezo-electric and electrostrictive materials.

The Dockyard Laboratory (Atlantic) has also been involved in transducer technology in its own right. The DL(A) conceived of an ultrasonic system for in-line sterilization of naval distillate and other fuels and managed a contracted feasibility demonstration.[23] Although the work demonstrated the technical feasibility of the concept, DGMEPM chose to rely on existing procedures, which involve careful husbandry of fuels and fuel systems, and the condemnation of contaminated fuels, or restriction of their use to non-military platforms without gas turbine machinery.[24] More recently (FY 00/01), DREA unsuccessfully proposed that the technology be applied to field sterilization of water in land-force operations. DGLEPM staff expressed satisfaction with current technology (reverse osmosis systems) and DSTHP expressed skepticism as to ultrasonic systems' capabilities against pathogens. DREA did not have funds available to sponsor testing against pathogens at DRES, and so DREA has entered into business development negotiations with the private sector, where there is interest in the technology for sterilization of food products. Should this business venture prove successful (both technically and commercially), it may be possible to spin the commercial technology back into military application.

DREA's Dockyard Laboratory (Atlantic) has a nascent program in functional materials independent of transducer requirements, that is being progressed primarily through collaboration with academia, in this case Acadia and Dalhousie Universities.

Both NRC/IAR and DREA's WSS section have interest in SMART structures, with the former's program being much more established.[25] The WSS interest to date is limited to applications of SMART composites for *in-situ*, in service performance assessment of structures, and active noise reduction. The IAR SMART structures activities have already seen application through collaboration with Bombardier/deHaviland on active noise control within the passenger cabins of Dash-8 aircraft.

[23] S Draisley and Mullins, M., Good Vibrations Engineering Limited, "Ultrasonic Destruction of Microorganisms in Shipboard Fuels Prototype Testing and Design of a Full Scale Flowthrough System – Phase 3," (Dartmouth, DREA Contractor Report CR 98/427, May 1998), LIMITED DISTRIBUTION. Patents in application.

[24] It is suspected that most condemned naval distillate ends up on the discount home heating fuel market!

[25] IAR assigns its SMART structures activities to the Platform Performance and LCM activity, rather than EM & BMT.

All of these activities suggest the organizational relationships given at Figure 1, with the following characteristics. First, RMC is a central element of the functional materials domain, being both within the academic community and a part of DND, with strong, established relationships with the US DoD, functional materials community. Unfortunately, this pivotal element depends upon one professor (Muhkerjee, Physics) supported by graduate students on a project basis. Additionally, a second professor (Ahkras, Civil Engineering) provides applications-oriented capability in civil engineering structures, and a third (Roberge, Chemistry and Chemical Engineering) has experience in the development of corrosion sensing technology for aircraft structures. Of these two, Roberge is most capable of providing additional support to more fundamental functional materials issues.

RMC has strong historical links to DREA's Transducer Group, courtesy of earlier sponsorship, and attempts are underway to build similar relationships with DREA's Dockyard Laboratory (Atlantic) (DL(A)). As an adjunct to RMC's strength in materials characterization, DREA DL(A)'s relationships with Dalhousie and Acadia Universities will position DL(A) to be DRDC's pivotal unit for expertise in functional materials. These other academic units concentrate more on materials formulation than characterization, and thus provide complementary competence to that of RMC.

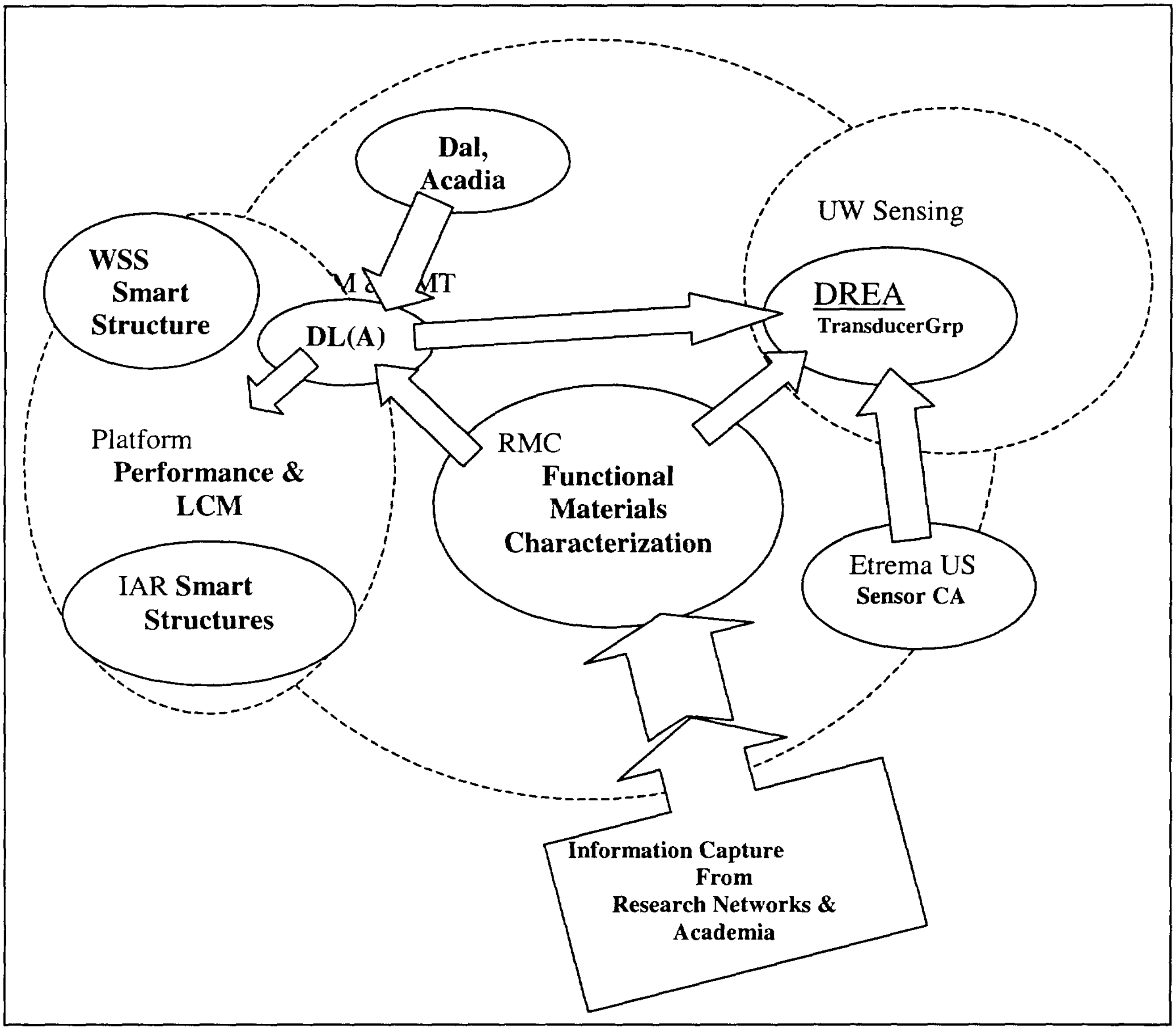

Figure 1: Organizational relationships for Focus A

DREA's Transducer Group and Warship Signatures and Safety Section, and NRC's IAR will be users of functional materials, but will require resident expertise for effective exploitation. Figure 1 does not show NRC's core expertise in functional materials, which provides core competency to IAR, in the same way that RMC and Dockyard Laboratory (Atlantic) do to DREA.

With guidance from ADM (S&T), the DRDC Technology Assessment Working Group prepared a straw-man Technology Investment Strategy that provided a number of investment options across all R&D Activities presented in the TIS:

- Status quo, which identified 7 FTEs assigned to EM & BMT at DREA,
- Scenario 1, that provided for redistribution of existing human resources, but made no adjustment to EM & BMT,
- Scenario 2, that added 160 new FTEs to Scenario 1 across all R&D Activities, but made no addition to EM & BMT,
- Scenario 3, that added 260 new FTEs to Scenario 1 across all R&D Activities, and apportioned 20 of the new FTEs to DREA, and a further 20 to DRES, and
- Scenario 4, that added 360 new FTEs to Scenario 1 across all R&D Activities, and apportioned 20 of the new FTEs to DREA and a further 30 to DRES.

Staffing options for Focus A were developed by apportioning the 7 and 27 FTE's between Foci A and B, and examining the roles of existing and future staff. The Status quo through Scenario 2 options represent current 'seed' competencies in DREA's DL(A) and EM/TR, and in RMC. The growth scenarios, 3 and 4, build upon these seed competencies. See Table 3.

Table 3: Staffing plans for Focus A

Scenario	**Unit**	**Staff** *(Incumbents italicized)*
Status quo	DREA/DL(A)	*Hyatt (DS)*
	DREA/EM/TR	*Purcell (DS), Reithmeier (EG)*
	RMC	*Muhkerjee (RMC-funded)*
Scenario 1 & 2	DREA/DL(A)	*Hyatt (DS)*
	DREA/EM/TR	*Purcell (DS), Reithmeier (EG)*
	RMC	*Muhkerjee (RMC-funded)*
Scenario 3 & 4	DREA/DL(A)	*Hyatt (DS)*, 2 new DS, new CS & 2 new EG
	DREA/EM/TR	*Purcell (DS), Reithmeier (EG)* & new CS
	DREA/WSS	1 new DS & 1 new CS (smart structures)
	RMC	*Muhkerjee (RMC funded)*, new research chair, new post-doc, 2 new research assistants (MSc or EG)

Hyatt would lead the development of an in-house program and team focused on functional materials *per se*, the core of focus A. As a starting point, the program of work might encompass topics such as:

- Magnetic shape memory materials,
- Toughness of magnetostrictive materials,
- Composite magnetostrictive and shape memory materials,
- Thin film shape magnetic memory alloys as a possible precursor to signature reduction coatings, multi-functional coatings, and applications to MEMS devices,
- Practical manufacturing of active materials through, for example: strip casting, crystal growth, etc.,
- Incommensurate phase- and quasi-crystals for signature reduction and bio-contaminant detection, and,
- Shape memory alloys 'by design.'

There would undoubtedly be considerable opportunity for collaboration, not only with RMC, but also through TTCP, particularly in light of the NAMRAD Principals direction to MAT Group to propose a way ahead in advanced materials. Fortuitously, Hyatt only recently was appointed Canadian National Leader, MAT TP-1 (Metals), which also addresses current activities in functional materials.

Scenarios 3 and 4 provide for the preservation and growth of the RMC materials characterization capability first established by DREA sponsorship. The importance of the RMC team cannot be overemphasized as a corporate link to academia and beyond. RMC is alone among Canadian academia in being within reach of an FE, and unencumbered by the constraints imposed by competitive contracting policies.

Finally, the small increases in staff assigned to DREA's EM/Transducers and WSS Sections provide the expert liaison with internal applications. The EM/Transducer effort is focused on transducer applications, a traditional DREA strength.[26] The WSS effort enables the extension of nascent finite element modeling capability in smart structures, which will support introduction of such structures into CF service.[27]

IAR activities are not addressed here, since NRC assigns them to another TIS activity.

7. Implementation Options for Focus B, Substitution of Conventional Materials by Tailored Polymers

Tailored polymers, or 'polymers by design', have also been subject to research within DRDC. The Dockyard Laboratory (Atlantic)'s Dr. Jeffrey Szabo has conducted research on damping and anechoic materials, and more recently been focus officer for a TTCP

[26] Sensing (Underwater), Focus A, "Affordable Distributed Sensors and Influence Sweeps" is the targeted 'client' activity in the TIS.
[27] Platform Performance and LCM, Focus B, "Structural Analysis for Life-Cycle Management and Insertion of Advanced Materials Technology," is the target client activity in the TIS

MAT, TP-6 (Polymers and Coatings) Operating Assignment on the modeling of polymeric damping materials.

More recently, Dr. Paul Saville of Dockyard Laboratory (Pacific) made a successful TIF application for work on organic radar absorbing materials. The proposal was originally written by Dr. Sandra Nevill, who is now on exchange with the US Naval Surface Warfare Center, Carderock, to undertake research on the environmental resistance of such coatings. Early indications are that the exchange will prove fruitful in building relationships between DRDC and US DoD in this technology area.

Figure 2, overleaf, suggests possible organizational relationships for Focus B, including the addition of NRC/IMI, which has collaborated with DREA/DL(A) on formulation of polymers, and University of Victoria, which is an important collaborator with DREA/DL(P) on the TIF project on organic radar absorbing materials.

Table 4, overleaf, shows staffing options for Focus B, based on the remainder of DREA staff apportioned to EM & BMT in the straw-man scenarios. Again, status quo through Scenario 2 represents current seed competencies that provide the leadership for growth in Scenarios 3 and 4. Separate teams are proposed for each Dockyard Laboratory, to provide continuing scientific support to consulting on each coast.[28] The two teams exploit existing research to build complementary competencies, with the DL(A) focused upon polymers by design and the DL(P) upon functional organic coatings and appliqués.

In DL(A), Szabo would lead the development of the larger of the two in-house programs and teams in Focus B, directed at polymers by design. As a starting point, the program of work might encompass topics such as:

- Modeling of polymer-based materials, including the effects of chemical structure on physical properties,
- Electroactive polymer actuators and devices,
- Polymer-based sensors for military applications,
- Optimized design and development of polymers for acoustic stealth applications, and
- Interpenetrating polymer networks for noise damping and other applications.

In DL(P), Saville would lead the smaller DL(P) program and team, directed at functional organic coatings and appliqués, with possible topics of research being:

- Obviously, radar absorbing materials,
- Functional appliqués (e.g.: ice-shedding, bio-fouling resistant, etc.), and
- Thin-film sensors.

[28] Platform Performance and Life Cycle Management, Focus D, "Materials and Materials Management for Platform and Systems Safety and Life-Cycle Management."

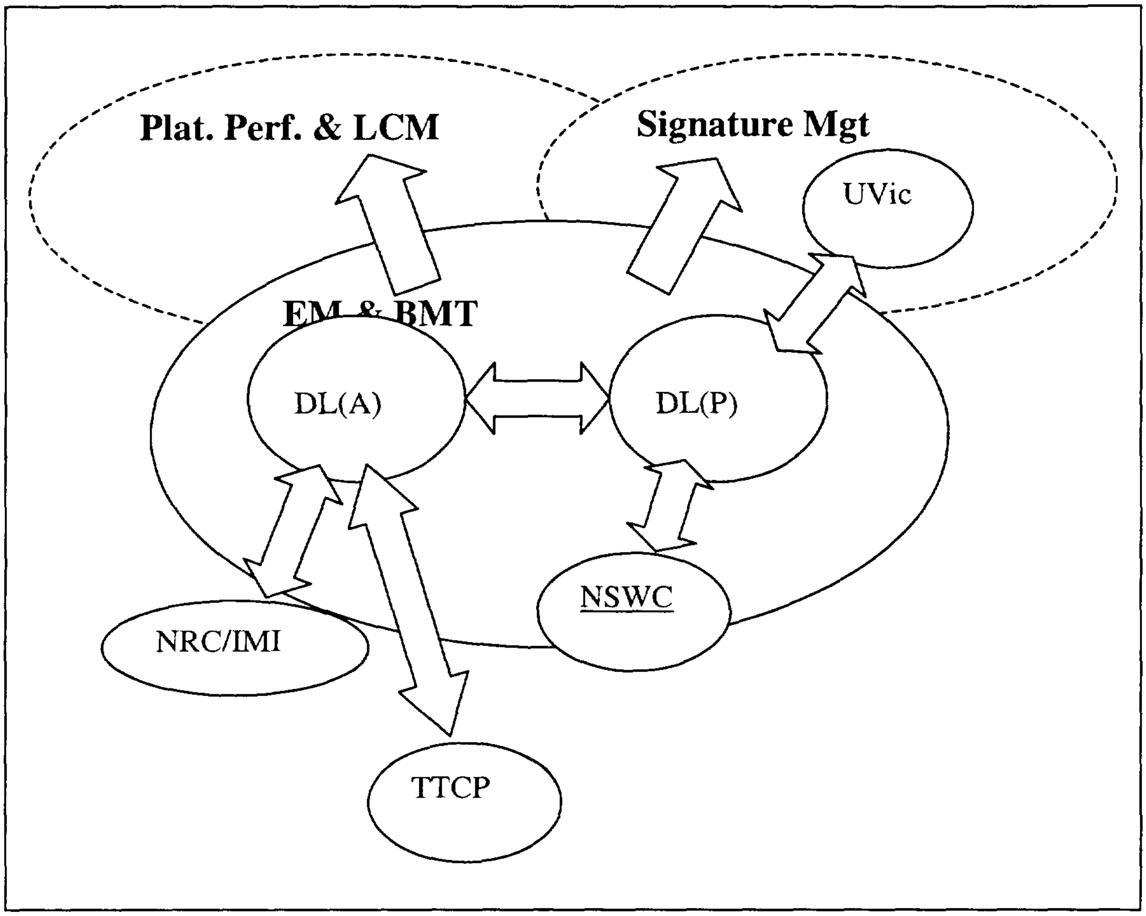

Figure 2: Organizational relationships for Focus B

Table 4: Staffing Plans for Focus B

Scenario	**Unit**	**Staff** *(Incumbents italicized)*
Status quo	DREA/DL(A)	*Szabo (DS) & Keough (EG)*
	DREA/DL(P)	*Saville (DS) & Blekinsop (EG)*
Scenario 1 & 2	DREA/DL(A)	*Szabo (DS) & Keough (EG)*
	DREA/DL(P)	*Saville (DS) & Blekinsop (EG)*
Scenario 3 & 4	DREA/DL(A)	*Szabo (DS)*, 3 new DS, 3 new CH *& Keough (EG)*
	DREA/DL(P)	*Saville (DS)*, 1 new DS, *Blekinsop (EG)* & 1 new EG

8. Implementation Options for Focus C (revised), Synthesis of Military Materials by Molecular Manufacturing

Initial versions of Focus C included manufacturing through bio-molecular technology, perhaps in recognition of the potential of biomimetics; however, reference to biotechnology was dropped in favour of a more capable biotechnology-directed Focus D. Focus C is now limited to molecular techniques alone, as conducted by NRC IAR. Work of this nature is directed towards first principles modeling and laboratory-level production of test materials. The leading application is aero engine high-temperature coatings; the 2001 TIF program supports such a project from IAR (Zhao: Modeling Single-Crystal Superalloy Properties).

The implementation plan for Focus C is based upon existing NRC/IAR program in aero-propulsor materials. NRC reports 9 FTEs engaged in the work, 6 being funded by IAR and 3 by DRDC.

Focus C (revised): Synthesis of Military Materials by Molecular Manufacturing Techniques: Military systems, particularly aeronautical, are significant users of high performance materials for tribological or combustion applications, but the most common of such materials are increasingly subject to environmental censure. Typically, such high-performance applications require combinations of toughness and hardness that are not feasible through bulk metallurgy, but such combinations of properties can be achieved through molecular-level material assembly. It is expected that work will initially focus on aeronautical applications, with spin-off to other applications and problems as experience develops.

9. Implementation Options for Focus D (new), Biotechnology for the Protection of CF Personnel

In the TIS, Focus C of EM & BMT is the only one explicitly addressing biotechnology, and then only peripherally. The focus addresses both 'molecular manufacturing' and 'bio-molecular technology' with the latter intended to address biomimetics. Focus C, as written, is a logical companion to the other two foci, but Sections 2 to 5 of this report indicate greater need for 'classical' biotechnology programs than implied by Focus C, as published in the TIS. Thus, a replacement to Focus C is proposed, as follows, and the implementation options are based upon the revised focus.

Focus D (new): Biotechnology for the Protection of CF Personnel: CF contingency and coalition missions take personnel into a broad range of environments presenting a broad challenge of endemic disease and other chemical and biological hazards. Biotechnology is the enabling technology which will provided needed advances in treatments, detection and identification technologies and diagnostics, to provide the Force Health Protection required by the CF. Biotechnology also has applications in materials sciences and in the production of coatings and materials which can improve permeability characteristics, filtration capabilities and performance in adverse environments.

This new Focus D provides a focal point for introduction of this key enabling technology of the future to DRDC in an area of critical importance to CF Forces. Additionally, the level of effort proposed would provide sufficient effort to exploit other opportunities arising. Clearly, Focus D would initially address the needs of Chemical/Biological/Radiological Threat Assessment and Detection (CBR) and Operational Medicine (OM), but undoubtedly other applications involving human interfaces would be identified over time. Indeed, there are prospects of introduction of biotechnology into sensing and the information sciences, but to add those goals to the present *raison d'être* is probably inviting failure through dilution of purpose.

In parlance introduced in Section 6 of this report, CBR and OM are client activities of EM & BMT. The first of these two client activities includes two relevant foci:

- CBR Focus B, Detection, Identification and Diagnostics, that includes reference to "fusion of nano- and bio-technologies into new sensors," and
- CBR Focus C, Individual and Systems Protection, that addresses systems level protection and advocates exploiting biotechnology and advanced materials for integrated coatings and sensors, that might be applied to future, 'low or zero-burden' combat ensembles, or the next generation of filtration devices.

The second activity includes broad reference to biotechnologies, but again the theme is dominant in two foci:

- OM Focus B, Toxicology and Pharmacology, that proposes use of advanced computational techniques in the design of therapies, but relies upon biotechnology to produce new therapies, and
- OM Focus C, Prevention and Treatment of Diseases, that notes that "biotechnology will be the dominant," presumably as the means of producing next-generation vaccines, antibiotics and antivirals.

In each of the two sets of preceding CBR and OM foci above, the most appropriate delivery agency for the work under the revised Focus D of EM & BMT would be DRES. The straw-man scenarios for EM & BMT provide no human resources for such work until scenarios 3 (20 FTEs) and 4 (30 FTEs), although in reality, there is nascent biotechnology research within the CBR and OM communities, albeit supported by TIF, rather than thrust funds. Following from concerns expressed in Section 2, provision of human resources under EM & BMT Focus C would allow transition from TIF investigations to core competencies.

Discussions with the Chief Scientist, DRES, suggest the need for more support to Operational Medicine than to CBR Threat Assessment and Detection, and a staffing ratio of 14/6 was agreed for Scenario 3. A corresponding ratio of 21/9 is adopted for scenario 4. Staffing plans follow, grouped by client activity, and indicating the appropriate host Section or Group at DRES.

The Detection and Identification Group at DRES (DRES/DIG) has, among other things, delivered a successful detection project under DARPA sponsorship. During Nethercote's visit to DRES, the group argued the benefits of technology exploitation over technology watch, with the DARPA project being a prime example of such activities. Technical currency is but one benefit, not to mention the obvious opportunities for revenue generation.

The Personal Protection Group is a small (5 FTEs) team focused upon integration of emerging technologies in combat ensembles. Scenario 3 could enable staffing of current, unfunded vacancies, to capture emerging technologies, with further minor augmentation in Scenario 4.

The Preventive Medicine Group (and probably the Medical Therapy Group) conducts R&D to provide treatments to reduce or eliminate operational effects of biological warfare and endemic disease hazards for the CF. This group (or groups) is the one most sensitive to biotechnology. The proposed growth includes the engineering, technologist and general services support associated with twinned level 3 bio-labs at DRES, to accommodate increased scientific capacity, and provide continuous facility availability through the year.

Table 5 provides the incremental staffing plans for Focus D at DRES, addressing topics of relevance to the three Groups described; however, it is proposed that the staffing not be assigned to existing Groups, but rather to a new Section, focused upon Biotechnology. Leadership of the new section would be drawn from the existing DRES Chemical and Biological Defence Section.

Table 5: Incremental staffing plans for Focus D

Scenario	**Unit**	**Staff**
Scenario 3	DRES/New Section	8 new DS, 8 new EG, 1 new Eng & 3 new GS
Scenario 4	DRES/New Section	15 new DS, 11 new EG, 1 new Eng & 3 new GS

10. Concluding Remarks and Recommendations

This report has surveyed a number of experts, both nationally and abroad, and made a limited survey of the literature to develop an appreciation of the emerging materials and biotechnology fields, and to develop an implementation strategy for EM & BMT in DRDC. En route, it became necessary to revise portions of the R&D Activity, as given in Section 8, and summarized in Annex A.

Growth in Focus A would be implemented at both DREA and RMC, providing critical mass for the formulation, characterization, and modeling of functional materials. Three DRDC-funded FTEs are now devoted to Focus A; DRDC-funded FTEs would increase to 15 in Scenarios 3 and 4. The initial target of the work would be transducers and smart structures.

Growth in Focus B would be implemented at DREA, in broadest terms addressing polymers by design. Four DRDC-funded FTEs are now devoted to Focus B; DRDC-funded FTEs would rise to 12 in Scenarios 3 and 4.

The originally published Focus C has been revised to reflect ongoing work at NRC/IAR in support of advance materials for aero-propulsors.

A new Focus D has been introduced to reflect a need for a more classical biotechnology effort within the DRDC program. This new biotechnology effort would be implemented as a new Section at DRES, initially focus on chemical and biological defence and operational medicine issues, but with expectation. No DRDC-funded FTEs are available now; Scenarios 3 and 4 provide 20 and 30 DRDC-funded FTEs respectively.

Focus D will provide a welcome addition to DRDC's capabilities, however it comes at the cost of limiting potential benefits in 'conventional' emerging materials to two fairly narrow areas; albeit ones staffed at a level appropriate to support real technological advancement and meaningful collaboration with allies. Foci A and B will enable more effective collaboration under TTCP MAT Group, but certainly will not be able to respond to more than a few of the opportunities currently being refused. In absence of resource constraints, Emerging Materials and Biotechnology would benefit greatly from being split, with each of the two components being supported by resources similar to the current activity, rather than sharing that number.

ANNEX A – A Revised R&D Activity

As a result of the studies reported in the main body of this report, revisions were made to the R&D Activity known as Emerging Materials and Biomolecular Technology. For completeness and clarity, the proposed revised text follows.

Emerging Materials and Biotechnology

Definition: This activity (area of competency) reflects the increasing importance of advanced or novel materials, whether organic or inorganic, in military or civil systems. Most contemporary advances in materials technology are not a response to a requirement, but instead, a technology driver. This is particularly true for biotechnology, where certain applications would simply be infeasible without a biotechnological basis Although this activity (area of competency) does not include the development of systems in the classical, linear RD & E sense, the conduct of technology demonstrations of application of emerging materials or biotechnology products would be necessary in addition to research in materials and biotechnology *per se*.[29]
Focus A: Functional Materials for Transducers, Actuators, and Smart Structures: The performance of functional materials is a key constraint on performance of transducers (such as sonar projectors) and actuators and signature control devices (such as active machinery mounts). Introduction of functional materials with higher than hitherto strains can have far greater benefit than any amount of ingenuity with transducer geometry and could lead, ultimately, to the development of structures capable of optimal response to external loads, or for use as fluid dynamic controls
Focus B: Substitution of Conventional Materials by Tailored Polymers: Such substitutions demand both careful selection and formulation of materials and re-examination of design parameters, so that materials capabilities are exploited optimally Tailored polymers will require development of advanced modeling techniques for the prediction of mechanical or chemical performance, and estimation of feasibility of formulation
Focus C: Synthesis of Military Materials by Molecular Manufacturing Techniques: Military systems, particularly aeronautical, are significant users of high performance materials for tribological or combustion applications, but the most common of such materials are increasingly subject to environmental censure. Typically, such high-performance applications require combinations of toughness and hardness that are not feasible through bulk metallurgy, but such combinations of properties can be achieved through molecular-level material assembly It is expected that work will initially focus on aeronautical applications, with spin-off to other applications and problems as experience develops.
Focus D: Biotechnology for the Protection of CF Personnel: CF contingency and coalition missions take personnel into a broad range of environments presenting a broad challenge of endemic disease and other chemical and biological hazards. Biotechnology is the enabling technology which will provided needed advances in treatments, detection and identification technologies and diagnostics, to provide the Force Health Protection required by the CF. Biotechnology also has applications in materials sciences and in the production of coatings and materials which can improve permeability characteristics, filtration capabilities and performance in adverse environments.

[29] The TIS indicated that "As a *modus operandi*, this R&D Activity would at most, conduct technology watch and 'pilot applications' of promising candidate materials, probably at a 'brass board' level, or ultimately through simulation, prior to passing the candidate material over to one of the more application-oriented activities for exploitation." It will be seen that the present study does not take the TIS too literally, indeed, some interviewees denigrated the utility of technology watch relative to technology exploitation, both as a means of maintaining technical currency, and as currency for scientific exchange with allies.

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An implementation strategy for Emerging Materials and Biotechnology, one of twenty one new R&D activities identified in the Defence Research and Development Canada (DRDC) Technology Investment Strategy, is proposed. The proposal recommends four foci for this new activity; Focus A - Functional Materials for Transducers, Actuators, and Smart Structures, Focus B - Substitution of Conventional Materials by Tailored Polymers, Focus C - Synthesis of Military Materials by Molecular Manufacturing Techniques, and Focus D - Biotechnology for the Protection of CF Personnel. The selection of foci was based on surveys of approximately 50 experts in these fields and a limited literature review. Straw-man research activities and levels of effort (with guidance from ADM S&T) based on possible scenarios for future staffing are delineated. It is recommended that Focus A be implemented at both DREA and RMC, Focus B be implemented at DREA, Focus C at NRC/IAR, and Focus D at a new Section at DRES.

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